CRREL REPORT 90-6

AD-A227 335

DTIC FILE COPY

CRREL

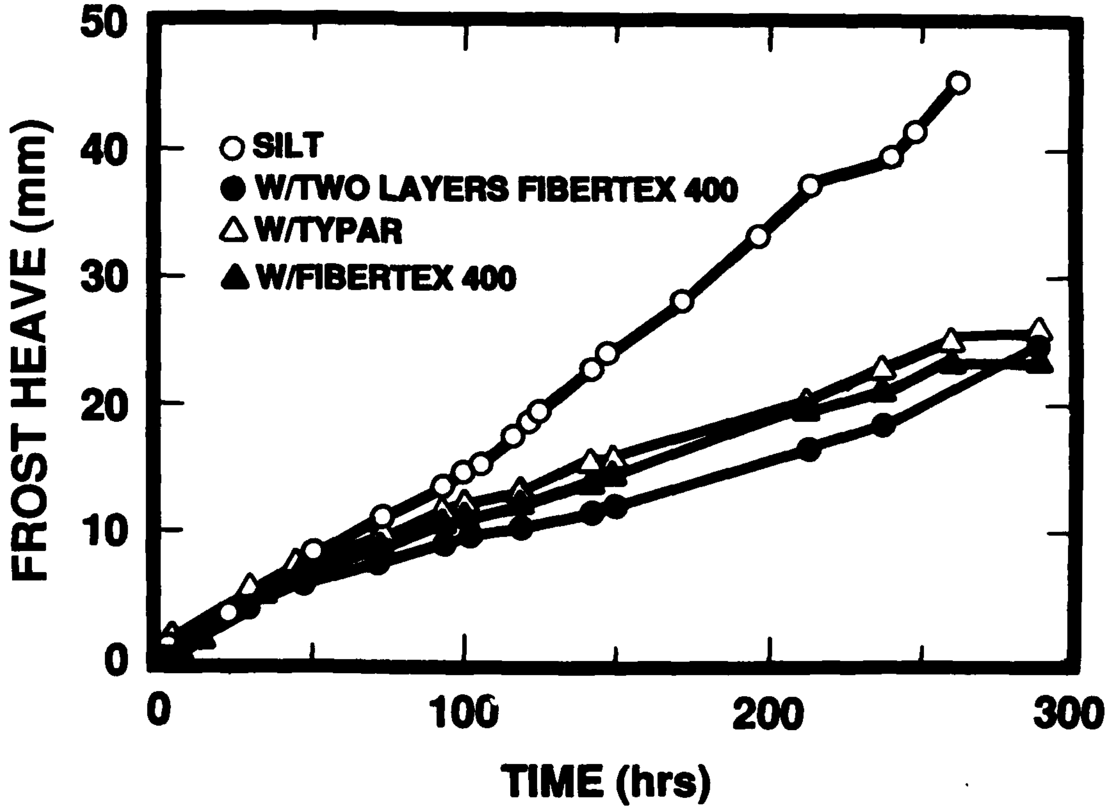
4

DTIC ELECTE OCT 11 1990 S B D

Laboratory Investigation of the Use of Geotextiles to Mitigate Frost Heave

Karen S. Henry

August 1990



Cover: Comparison of the frost heave experienced by silt samples containing various types of geotextiles with the frost heave experienced by a control sample.

CRREL Report 90-6

U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Laboratory Investigation of the Use of Geotextiles to Mitigate Frost Heave

Karen S. Henry

August 1990

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

Approved for public release; distribution is unlimited.

PREFACE

This report was prepared by Karen S. Henry, Research Civil Engineer, Civil and Geotechnical Engineering Research Branch, Experimental Engineering Division, of the U. S. Army Cold Regions Research and Engineering Laboratory, at Northwestern University under the sponsorship of the Federal Aviation Administration and the U.S. Army Corps of Engineers. USACE funding was provided by DA Project, *Operations and Maintenance, Army, Facilities Investigation Studies*, 722894.M7, *Construction Support Studies*; Work Unit, *Use of Geotechnical Fabrics to Minimize Seasonal Frost Effects*.

The following people reviewed this report: Dr. Charles Dowding, Dr. Barbara Ann-G. Lewis and Dr. Jorg O. Osterberg of Northwestern University, Evanston, Illinois, and Dr. Patrick Black of CRREL. Dr. Richard Berg, Edwin Chamberlain, Richard Roberts, Jonathan Ingersoll, Rosanne Stoops, Matthew Pacillo, Edward Perkins, William Bates and Jacqueline Castor of CRREL contributed to this research effort.

The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.

NOMENCLATURE

A	cross-sectional area
Cu	coefficient of uniformity
d	head loss
D_{10}	size of screen opening passing 10% by weight of a soil sample
D_{60}	size of screen opening passing 60% by weight of a soil sample
G_s	specific gravity
h_c	capillary rise in a tube
k	hydraulic conductivity
L	distance
P	vapor pressure
P_o	reference vapor pressure
Q	volumetric quantity of water flow
R	gas constant
r	radius of capillary tube
S	entropy
T	temperature
t	time
T_s	surface tension of liquid
V	volume
α	contact angle between liquid and solid
γ	unit weight
γ_d	unit weight of dry soil
μ	chemical potential
μ_o	chemical potential for a pure phase at a reference state
μ_v	chemical potential of water vapor

CONTENTS

ILLUSTRATIONS

TABLES

Laboratory Investigation of the Use of Geotextiles to Mitigate Frost Heave

KAREN S. HENRY

INTRODUCTION

Frost action in frost-susceptible soils can seriously damage highway and airport pavements, causing differential heaving and buckling of pavements during winter periods as well as softening of entire pavement sections during spring thaw. These effects can result in pavement cracking and failures such as potholes and pumping of saturated fine-grained soils through the cracks with the passing of traffic. Furthermore, differential frost heaving in the winter may make the pavement rough and traveling hazardous.

The main objective of this laboratory study was to assess the ability of certain geotextiles to mitigate frost heave in soils. It is hypothesized that geotextiles can act as capillary breaks to reduce the unsaturated flow of water to the freezing front.

Early theoretical work and some of the most recent theory regarding frost heave is presented, as is a review of geotextile properties that most influence their behavior as capillary breaks when emplaced in frost-susceptible soil. Also reviewed are the results of laboratory and field studies that have examined the use of geotextiles for frost heave reduction.

LITERATURE REVIEW

Whenever air temperatures fall below freezing, especially for more than a day, there is a good chance that pore water in the soil will freeze. Freezing temperatures in the ground are known to cause migration of water to the region where ice is crystallizing (the freezing front), forming ice lenses that cause frost heave. It is not uncommon for water contents in heaving soils to increase by tenfold.

Soils that are fine grained, but not highly plastic (i.e., silts), are usually the most frost-susceptible. Generally, coarse-grained soils do not heave, and the heaving of plastic soils is small compared to silts. There are many soil classifications that attempt to indicate whether a soil will heave. Most soils classified as non-frost-susceptible do not heave; however, soils classified as frost-susceptible may or may not heave. Engineers have turned to laboratory testing to more accurately classify heave susceptibility. However, laboratory-based classification is not 100% successful and there are many laboratory methods for estimating the frost-susceptibility of soils (Chamberlain 1981).

In addition to a frost-susceptible soil type and freezing temperatures, water must be available to the freezing front for frost heave to occur. If a soil is not saturated, this water can be provided by capillary rise and from water films adsorbed on soil particles, and a small portion may come from moisture vapor.

Although frost heave has been observed for some time, it was not practically or economically important until the early twentieth century when the advent of the automobile spurred the development of highways (Beskow 1935). Frost action in the subgrade is a major cause of damage to pavements in regions where soil freezes. (When base and subbase layers also contain large amounts of fines, making them frost-susceptible, problems are exacerbated.) Damaging effects include differential frost heaving leading to unsafe conditions and possibly even buckling of the surface as well as subgrade softening and pavement failure during the spring melting period. During the melting period, water becomes trapped above a deeper, frozen surface. This causes weakening of pavement layers and may be accompanied by the development of

"frost boils"—the breaking of sections of pavements under traffic loads resulting in the ejection of soft, semi-liquid soil (Berg and Johnson 1983).

In the following sections, a current theory of frost heave is discussed, some of the means by which the frost-susceptibility of a soil is estimated are described, geotextiles and geotextile properties are reviewed, and past results of laboratory and field studies using geotextiles to reduce frost heave are summarized.

Frost heave theory

Taber (1930) was one of the first researchers to systematically study frost heave. One of his most significant contributions was the observation that in heaving soils, the surface uplift equaled the total thickness of ice layers developed. Taber also (accurately) proposed the idea that frost heave was influenced by the rate of freezing of soil water and mobility of water molecules in films adsorbed on soil particles.

Beskow (1935) postulated that, for frost heave to occur, a water film must exist between ice and soil particles. He explained the process of water migration by speculating that if there is a temperature depression near an ice crystal, the nearest water molecules in an adsorbed film enter the crystal structure, decreasing the adsorbed water film thickness. This leads to increased suction in the film, which causes water migration. Later experimental work verified the existence of water films by examining particle migration through ice and particle rejection by a growing ice lens (Corté 1962, Hoekstra and Miller 1967).

Gold (1985) summarized the following six characteristics of water freezing in porous material, which were stated or implied in the combined contributions of Taber (1930) and Beskow (1935) and later verified by experiment.

1. Ice lense formation implies a mobile film between the ice and the solid surfaces on which it is supported.

2. Applying pressure in the direction of freezing or increasing the pore water tension, or both, can stop ice segregation.

3. The pressure or tension required to stop formation of ice lenses generally depends on grain size—the smaller the average grain size, the more pressure or tension is required.

4. Not all soil water freezes at 0°C (32°F). Unfrozen water content is related to porosity, pore size distribution and the nature of the soil material.

5. Freezing occurs over a zone, the depth of which is influenced by soil properties, applied pressure, pore water tension and temperature gradient.

6. The front of a growing ice lens does not necessarily coincide with the plane in which pore ice first begins to form. Neither the ice front nor the freezing front need coincide with the 0°C isotherm.

Beskow (1935) also showed why silts are more frost-susceptible than either more coarse soils or clays by examining the effect of average grain size on the rate of capillary rise. As grains decrease from sand to silt size, the rate of capillary rise increases. As the grains continue to decrease to clay size, the rate of capillary rise decreases. Beskow showed experimentally that rate of capillary rise is maximum for silt-sized particles, and significant flow rates can be sustained when the height of capillary rise equals or exceeds the depth to the water table.

The remainder of this section will deal with the theory that was developed from the above observations. This background is meant to provide a conceptual framework for the frost heave process.

Some of the aspects of frost heave that most intrigue geotechnical researchers are the mechanisms by which water migrates to the freezing front. This process can be explained qualitatively using concepts from equilibrium thermodynamics, even though thermodynamic equilibrium is probably never achieved in a heaving soil (Gold 1985). Gold (1985) provides an excellent review and summary of current knowledge in this area.

The assumption is made that there exists a homogeneous, moist soil body in contact with a water supply under a temperature gradient adequate to maintain freezing. Gold (1985) explains the water migration process by considering the chemical potential μ of water films adsorbed on soil particles that are in contact with ice, other soil particle films or free water in the soil, or all three. A gradient in the chemical potential of a substance causes the substance to migrate in the direction of lower chemical potential, and phase change will occur to the phase of lower chemical potential when two phases are in contact. For a single chemical species, the Gibbs–Duhem relation gives the dependence of chemical potential change on pressure and temperature (Gold 1985)

$$d\mu = VdP - SdT \qquad (1)$$

where V = molar volume of phase
S = entropy per mole
dP = change in pressure
dT = change in temperature.

If V and S are taken to be constant (reasonable assumptions over a small range in temperature), eq 1 can be integrated to obtain (Gold 1985)

$$\mu = \mu_o + V\Delta P - S\Delta T \qquad (2)$$

where μ_o = chemical potential for a pure phase at 0°C (32°F) and 1 atm (101 kPa), or some other reference state.

Equations 1 and 2 show that changes in pressure and temperature of a pure substance will cause chemical potential to vary, leading to mass migration or phase change, or both. An increase in pressure or decrease in temperature results in an increased chemical potential. However, it may be assumed that the temperature gradient is small near the freezing front.

At a constant temperature, the change in the chemical potential of water vapor because of a change in pressure from the reference state is (Gold 1985)

$$\Delta\mu_v = R\,T\ln\left(\frac{P}{P_o}\right) \qquad (3)$$

where R = the gas constant
T = absolute temperature
P = vapor pressure
P_o = reference vapor pressure.

Remembering that at equilibrium the liquid and vapor phases have equal chemical potentials, we can see from eq 3 that a decrease in the pressure of films adsorbed on soil particles (hereafter called adsorbed films) will result in a decreased chemical potential. Thus, a decrease in film pressure leads to transport of water to the lower pressure site from adjacent films (Gold 1985).

In unsaturated soils, a decrease in water content (and, therefore, adsorbed film thickness) corresponds to a decrease in soil water pressure (increased soil matrix suction) (Hillel 1982). As water moves from the adsorbed films to an ice lens and changes phase at the freezing front (the ice having a lower chemical potential), water will migrate from adjacent films to the region of decreased film thickness (i.e., lower chemical potential).

When the water supply to a growing ice lens is *not adequate to continue the rate of thermal energy* being transported to the surface, i.e., the latent heat of fusion released does not balance upward thermal energy transport, an isothermal surface will descend through the soil until it reaches a point where the water supply is adequate for ice lens formation (Gold 1985).

Having discussed water migration to a growing ice lens, we now consider conditions of ice segregation initiation. Gold (1985) states that an ice lens begins to form when the "average disjoining pressure" over a constant temperature surface equals or exceeds the "average" effective stress at that surface. Disjoining pressures occur between films that are adsorbed onto soil particles and are to a large degree the result of repulsive electrical forces that arise from overlapping ion distribution (Derjaguin and Melnikova 1958). They are related to soil water chemistry, vapor pressure and capillarity, and are mobilized only "... upon attempts to thin a layer of water bounded by two phase interfaces..." (Derjaguin and Melnikova 1958). Derjaguin and Melnikova (1958) is recommended for further reading about the nature of disjoining forces.

Applying pressure in the direction of freezing or increasing soil moisture tension will increase the effective stress and therefore reduce the tendency of a soil to heave. Since "average" effective stress in a soil varies, especially with changes in density, soil type (grain shape and size) and water content, differential heave can occur as these parameters vary. One practice used to minimize differential heaving is to compact soil to a uniform density that is near optimum to maximize both strength and uniformity.*

Gold (1985) states that the relatively large surface area and thicker adsorbed films of silty soils increase the possibilities for water to move through the freezing zone. Furthermore, other considerations indicate that the finer the pores, the larger the disjoining pressures exerted. Based on these statements, we can expect that, in general, fine-grained soils will be more frost-susceptible than coarse-grained soils.

One of the properties of adsorbed water is a depressed freezing point. For this reason, as well as the fact that soil water contains chemical impurities, not all soil water freezes at 0°C (32°F). When ice crystallizes, it expels solutes at a rate that depends on the freezing rate (e.g., Mahar et al. 1982). Hallet (1978) showed that solute concentration at the freezing front can be significant for "normal" soil water, which would cause a local depressed freezing point. For these reasons, the front of a growing ice lens is probably not at the 0°C isotherm but behind it.

* Personal communication with R. Berg, CRREL, 1986.

Additionally, adsorbed soil water between ice lenses may not freeze.

To summarize the frost heave theory presented in this section, a chemical potential gradient leads to the migration of water in the direction of lower chemical potential, assuming a constant temperature over a relatively short distance. When water supply is not adequate at the freezing front to satisfy the rate of thermal energy transport to the surface, the temperature of the ice/water interface will drop. This increases the chemical potential of the water at the interface and water will no longer flow to this region. The freezing surface will drop to a location where the water supply rate is adequate for ice lens formation. Not all soil water freezes at 0°C because adsorbed water has a depressed freezing point and impurities in soil water are expelled by crystallizing ice. A growing ice lense in soil is located behind the 0°C isotherm location.

Frost-susceptibility determinations

In a comprehensive review of index tests that indicate the frost-susceptibility of soil, Chamberlain (1981) summarized over 100 methods used to determine soil frost-susceptibility. He found that there are five different bases for index tests: 1) particle size characteristics, 2) pore size characteristics, 3) soil–water interaction, 4) soil–water–ice interaction and 5) amount of frost heave.

The laboratory and field analyses in this report utilize index tests that are based on particle size information as well as laboratory frost heave tests; these tests are discussed below.

According to Casagrande (1931), under natural freezing conditions and with a sufficient water supply, there should be considerable ice segregation in nonuniform soils having more than 3% of grains smaller than 0.02 mm and in very uniform soils having more than 10% smaller than 0.02 mm. Although Casagrande (1931) does not quantify soil uniformity, Chamberlain (1981) quotes Riis (1948) in defining uniform soils as those having a coefficient of uniformity *Cu* of less than 5; *Cu* is defined as D_{60}/D_{10} where D_{60} is the size of screen opening corresponding to 60% of the sample passing by weight in standard sieve analysis and D_{10} is defined analogously. The Casagrande Criterion is the simplest and most widely used frost-susceptibility test; therefore, it is included in the analyses of this report.

The U.S. Army Corps of Engineers frost design soil classification is presented in Table 1 (Berg and Johnson 1983). Soils are listed in approximate order of decreasing bearing capacity during thaw—this is also a general indication of susceptibility to frost heave, although soils in groups F3 and F4 are roughly equal in propensity to heave.

Chamberlain (1981), stating that laboratory frost heave tests are perhaps the most direct way of determining the Frost-Susceptibility (FS) of soils, outlines the three basic types of laboratory frost heave tests: 1) those involving step changes in cold side temperature and observations of heave with time as thermal equilibrium is established, 2) those using a constant rate of frost penetration and 3) those using a constant rate of heat removal. The laboratory frost heave test used in this research (the standard CRREL frost heave test) utilizes a constant rate of frost penetration.

The standard CRREL frost heave test was developed by one of the parent organizations of CRREL, the U.S. Army Arctic Construction and Frost Effects Laboratory. The U.S. Army Corps of Engineers has been using it, with various modifications, since 1950 as a standard means of assessing the FS of soils (Chamberlain 1981). The most recent test details are presented in Chamberlain and Carbee (1981).

The CRREL frost heave test applies a combination of freezing, moisture and surcharge conditions, which are very conducive to frost heaving in a soil (Chamberlain and Carbee 1981). The results of the test do not predict actual frost heave in the field, but are used to indicate relative frost-susceptibility of the soil. Test details are discussed in the *Laboratory Frost Heave Tests* section.

In summary, the many frost-susceptibility tests available have one of five bases—1) particle sizes, 2) pore sizes, 3) soil–water interaction, 4) soil–water–ice interaction and 5) frost heave. The present research makes use of of three tests—two simple tests based on particle size distribution and the standard CRREL frost heave test.

Use of geotextiles to mitigate frost heave

The placement of layers of clean sands and gravels in frost-susceptible materials has been known to reduce frost heave (Rengmark 1963, Taivenen 1963). It is thought that, when placed above the water table and below the depth of frost penetration, coarse granular material reduces frost heave by breaking the capillarity and thereby limiting water available to the freezing front (e.g., Rengmark 1963). Thus, these layers are called "capillary breaks." Since many geotextiles have hydraulic conductivities on the order of clean, medium to fine sands

Table 1. U.S. Army Corps of Engineers frost design soil classification (after Berg and Johnson 1983).

*Frost group**		*Kind of soil*	*Percentage finer than 0.02 mm by weight*	*Typical soil types under Unified Soil Classification System*
NFS	(a)	Gravels Crushed stone Crushed rock	0–1.5	GW,GP
	(b)	Sands	0–3	SW,SP
PFS	(a)	Gravels Crushed stone Crushed rock	1.5–3	GW,GP
	(b)	Sands	3–10	SW,SP
S1		Gravelly soils	3–6	GW,GP,GW-GM,GP-GM
S2		Sandy soils	3–6	SW,SP,SW-SM,SP-SM
F1		Gravelly soils	6–10	GM,GW-GM,GP-GM
F2	(a)	Gravelly soils	10–20	GM,GW-GM,GP-GM,
	(b)	Sands	6–15	SM,SW-SM,SP-SM
F3	(a)	Gravelly soils	Over 20	GM,GC
	(b)	Sands, except very fine silty sands	Over 15	SM,SC
	(c)	Clays, PI > 12	—	CL,CH
F4	(a)	All silts	—	ML,MH
	(b)	Very fine silty sands	Over 15	SM
	(c)	Clays, PI < 12	—	CL,CL-ML
	(d)	Varved clays and other fine-grained, banded sediments	—	CL and ML; CL,ML, and SM; CL,CH, and ML; CL,CH,ML and SM

*NFS—non-frost-susceptible; PFS—possibly frost-susceptible, but requires laboratory test to determine frost-design soil classification; S1—gravelly soils with low to medium frost-susceptibility, suitable subbase materials; S2—sandy soils with low to medium frost-susceptibility, suitable subbase materials; F1—frost-susceptible gravelly soils; F2—frost-susceptible soils that when unfrozen behave as GM, GW–GM, GP–GM, SM, SW–SM or SP–SM materials; F3—medium to high frost-susceptibility; F4—high to very high frost-susceptibility.

(Bell et al. 1980), it is reasonable to test geotextiles for use as capillary breaks. Additionally, if a geotextile has a lower affinity for water than the soil particles, its ability to act as a capillary break will be enhanced.

The results of laboratory work that tested certain geotextiles as capillary breaks in freezing soils are promising (e.g., Allen et al. 1983, Chamberlain 1986). The results of two field installations of geotextiles to reduce frost heave have been reported and are also promising, although they did not directly consider the capillary behavior of the fabrics (Hoover et al. 1981, Andersson and Freden 1977).

The remainder of this section first considers geotextile properties that are significant to their behavior as capillary breaks, then reviews previous laboratory and field work.

Geotextile properties relevant to capillary break behavior

The physical properties of geotextile fabrics that are important to their ability to work as a capillary

break include (transverse) hydraulic conductivity, resistance to clogging and blinding, threshold pressure and separating ability.

Clogging refers to the trapping of soil particles within a fabric's pores, thus reducing its permeability, whereas blinding refers to the plugging of entrances to pores by soil particles at the fabric surface (Bell et al. 1980). The threshold pressure is the pressure required to initiate flow through a fabric and is related to the pore size and wettability of the fibers. A means of measuring this property has not yet been standardized (Bell et al. 1980, Allen 1986). Separation is the term applied to the function of fabric as a partition between two adjacent materials to prevent mixing of the materials (Bell et al. 1980). The term separation is different from "filtration" when applied to geotextiles. Filtration refers to the process of allowing water to escape easily while retaining the soil in place.

A geotextile's properties result from the construction of the fabric and the nature of the filaments (Bell et al. 1980). There are two main types of fabric construction—woven and nonwoven. Some fabrics are constructed by combining more than one method. Woven fabrics and fabrics constructed using combined methods are the most expensive. Woven fabrics have not proven to be as effective as capillary breaks as nonwoven fabrics in preliminary laboratory tests (Allen et al. 1983).* For these reasons, woven and combined fabrics were eliminated from testing in this study.

Nonwoven filaments are bonded together in one of four ways: needle-punching, heat bonding, resin bonding or a combination of these methods. Needle-punching consists of punching barbed needles through the fabric normal to the plane of the fabric so that the fibers become entangled. This technique results in a fabric thick for its weight with a complex pore structure subject to change upon being compressed (Bell et al. 1980). Generally, needle-punched fabrics are quite permeable.

Heat bonding (or melt bonding) occurs when the fabric is subjected to very high temperatures so that the filaments weld together at contact points. Thus, relatively thin fabrics are formed with the fibers being physically attached to each other. Heat bonded fabrics tend to have lower hydraulic conductivities than needle-punched fabrics.

Resin bonding refers to the use of a resin to coat fibers and cement them together. The thickness of the fabrics varies, depending on the pressure used in the bonding process, so that the fabric may be thin and dense or thick and open. Resin bonding results in fewer voids and, therefore, lower hydraulic conductivities than melt bonding or needle-punching.

Table 2. Geotextiles selected for frost heave investigations by Allen et al. (1983).

Geotextile name	*Fiber polymer*	*Geotextile construction*	*Nominal weight (oz/yd)*	*(gm/m)*
Nonwoven				
Bidim C-34	Polyester	Needle-punched Continuous filaments	272	8.00
Stabilenka T-100	Polyester	Resin bonded Continuous filaments	100	2.94
Typar 3401	Polypropylene	Heat bonded Continuous filaments	136	4.00
Fibretex 300	Polypropylene	Needle-punched Continuous filaments	300	8.82
Woven				
Propex 2002	Polypropylene	Woven Slit film	150	4.41

Bell et al. (1980) report that the two most common polymers in geotextile filaments manufactured in the United States are polypropylene and polyethylene. Polypropylene has a lower affinity for water than does polyethylene. Needle-punched and heat-bonded polypropylene materials are therefore chosen as likely candidates for capillary breaks because of their surface property of low water affinity and relatively large hydraulic conductivities.

Little is known about the surface properties of geotextile filaments since surface properties depend on the fiber finishing process as well as the type of polymer used. Information regarding surface charge would be useful because charged fiber surfaces may attract or repel fine soil particles (which are usually charged). Additionally, knowledge of the wetting angle of the fiber would be helpful in determining the ease of wetting of the material.

Laboratory studies

In a laboratory study, Allen et al. (1983) evaluated the use of geotextiles to reduce frost heave in soil. The frost heave and water content distribution in soil samples, which were frozen with geotextiles

* Personal communication with E. Chamberlain, CRREL, 1986.

Table 3. Percent reduction in heave rate and volume of water drawn into soil specimen (above the plane of the geotextile layer) due to geotextile layer (after Allen et al. 1983).

Geotextile type	*Reduction in heave rate due to geotextile layer*	*Reduction in volume of water drawn into soil specimen due to geotextile layer*
Bidim C-34	72.9	25
Stabilenka T-100	-22.4*	3
Typar 3401	82.8	33
Fibertex 300	85.5	23
Propex 2002	52.1	18

*Heave rate increased.

in place, were compared to those of a sample that did not contain fabric. Five different geotextiles were tested in this manner. Information about the fabrics tested and their general construction is presented in Table 2, and the results of the tests are given in Table 3.

They found that the geotextiles that reduced frost heave the most were either thick and permeable as well as hydrophobic or were "strongly hydrophobic" and relatively impermeable, i.e., Fibertex 300 and Typar 3401 respectively. One geotextile actually seemed to increase heave—Stabilenka T-100, the polyester geotextile, described by Allen et al. (1983) as "hydrophilic."

Allen qualitatively evaluated the "hydrophobicity" of the materials used by casually observing the behavior of water on the surface of these materials.* There is no standard evaluation of the hydrophobicity of geotextiles, and this property will vary with the filament material and the surface finish of the filaments as discussed in the previous section.

A strongly hydrophobic fabric with low permeability may have unwanted ponding of water above a horizontal layer of fabric.*† Ponding would be expected if the level of water trapped above the fabric did not rise above that required to produce the "threshold pressure" required to initiate flow through the fabric.

Roth (1977) tested in the laboratory the effectiveness of a capillary break consisting of a gravel layer encapsulated in a filter fabric. In this experiment the filter acted as a separator to prevent fines from contaminating a gravel layer placed within a frost-susceptible soil sample. The samples were frozen from the top with a water supply available at the bottom. No tests utilizing only the filter fabric or only the gravel were conducted, so it is not known if the fabric was part of the capillary break.

Roth's experiments revealed that the fabric-encapsulated gravel did prevent frost heave. They also suggested that the optimum position of the capillary break is above the water table but just below the depth of frost penetration. If the gravel layer was placed very deep, so that the frost line remained considerably above it, ice lenses would be likely to form from water in the fine-grained soil located above the gravel layer (Roth 1977). Unfortunately, Roth published no details regarding the filter fabric used in his test.

Figure 1 presents the experimental results of standard CRREL frost heave tests on sandy soil with three different polypropylene geotextiles inserted into the samples. The engineering properties of two of the fabrics used, Mirafi 600x and Fibertex 400, as provided by the manufacturers, are listed in Table 4. The only difference between Fibertex 400 and Fibertex 200, the third geotextile used, is that Fibertex 400 is twice as thick as Fibertex 200.

The frost heave test results presented in Figure 1 suggest that, given the same geotextile (specifically, Fibertex) and soil type, doubling the thickness of the geotextile will approximately double its effectiveness in mitigating frost heave. Furthermore, the woven, relatively low permeability geotextile was not as effective as the Fibertex needle-punched geotextile (which has a higher hydraulic conductivity) in reducing frost heave. This may be attributable to the increased complexity and size of pores of the Fibertex compared to Mirafi, both possibly making unsaturated water migration more difficult. Unquantified surface properties may also play a role.

Hoover et al. (1981) reported on a combined laboratory and field study that examined the ability of a geotextile to act as interlayer reinforcement in the construction and maintenance of roadway sections. The geotextile they tested was Mirafi 140, a nonwoven, heat-bonded fabric made of polypropylene and nylon-sheathed polypropylene fibers.

* Personal communication with T. Allen, Washington State Department of Transportation, Olympia Washington, 1986.

† Personal communication with E. Chamberlain, CRREL, 1986.

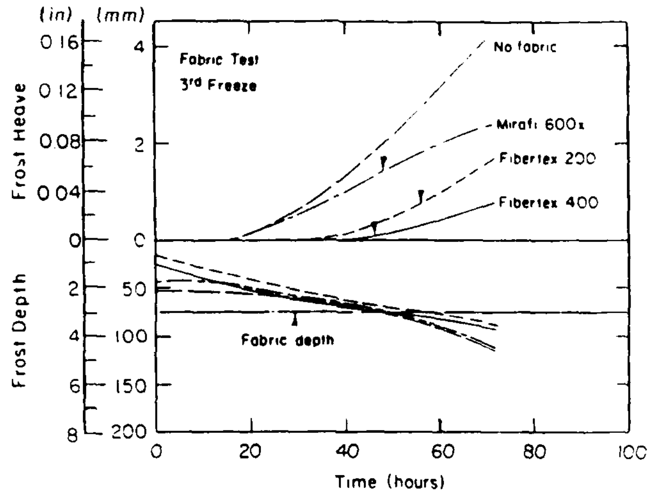


Figure 1. Results of standard CRREL frost heave tests conducted on a sandy soil with three different geotextiles (modified from unpublished data of E.J. Chamberlain, CRREL, 1986). Arrows on frost heave curves indicate time when frost (0 C [32 F] isotherm) penetrated fabric.

Table 4. Some engineering properties of Mirafi 600x and Fibertex 400 as provided by the manufacturers.

Geotextile	*Construction and material*	*Cost ($/yd²)*	*Cost ($/m²)*	*Thickness (mils)*	*Thickness (cm)*	*Hydraulic conductivity (cm/s)*	*Equivalent opening size (U.S. Standard Series)*
Mirafi 600x	Woven polypropylene	0.80	0.66	15	0.381	0.01	20–145
Fibertex 400	Needle-punched polypropylene	1.40	1.17	30	0.076	0.3	100+

The average pore size of the fabric was that of a medium fine sand.

Their laboratory study employed freeze–thaw tests to measure the heave of specimens as well as mechanical tests to determine various shear and stability parameters. In the freeze–thaw tests, silty clay soil samples were frozen from the top while water was constantly available at the bottom of the specimen. Single-layer thicknesses of fabric were inserted at various locations in the samples, which were compacted in three layers. Results of the freeze–thaw tests are presented in Figure 2. Note that the sample that heaved the least had two layers of fabric—each was located at one-third points in the sample.

In addition to reducing frost heave, the presence of fabric improved all stability and strength parameters of the soil in the laboratory. Hoover et al. (1981) attribute the results of the freeze–thaw tests to a combination of reduced sample capillarity and reinforcement.

Field studies

The field portion of the study conducted by Hoover et al. (1981) monitored the performance of fabric-reinforced test sections that were left in place for 20 months, through two winters. The geotextile was used in three different configurations. In one it was placed between a frost-susceptible subgrade and 0.6 m (24 in.) of coarse aggregate that was overlain by a 0.15 m (6 in.) surface course of soil aggregate. In another section it was placed between the frost-susceptible subgrade and the soil aggregate surface. In a third configuration, the fabric was placed on a frost-prone subgrade and overlain by 0.2 m (8 in.) of macadam base and 0.1 m

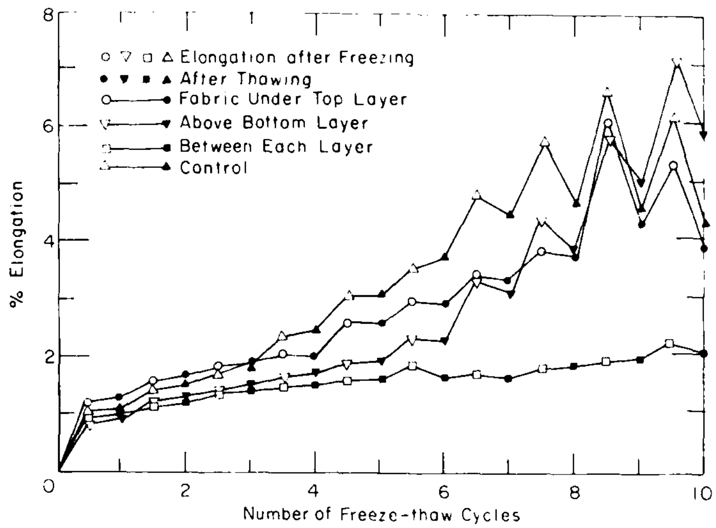


Figure 2. Results of freeze–thaw tests on soil samples with filter fabric inserts (after Hoover et al. 1981).

(4 in.) of choke stone. They did not measure frost heave. They did determine density, moisture content and percent of fines at various depths at the time of construction (October 1976) and 20 months later (June 1978). Periodically, they conducted in-situ mechanical and laboratory tests on undisturbed roadway samples.

Based on their field study, Hoover et al. (1981) concluded that the fabric performed best as a reinforcement between the soil-aggregate surface and a frost-prone subgrade, and that the use of a fabric in combination with a granular or macadam subbase was not justifiable, regardless of where the fabric was placed. Additionally, they concluded that the use of the fabric with non-frost-susceptible subgrades was not warranted. It is also interesting to note that they found evidence of migration of fines through the fabric.

A pilot study conducted in Sweden investigated the use of reinforcing fabric in five pavements constructed on a highly frost-susceptible subgrade (Andersson and Freden 1977). The pavement sections were frozen in a test pit consisting of five 2.5- × 2.5-m (8.2- × 8.2-ft) sections, each 1 m (3.3 ft) deep (Fig. 3). The test pit was insulated on all sides and a water table was held at a constant height of 10 cm (3.9 in.) as shown. The sections were frozen from the surface downward with refrigeration equipment over 3 to 4 months (Andersson and Freden 1977).

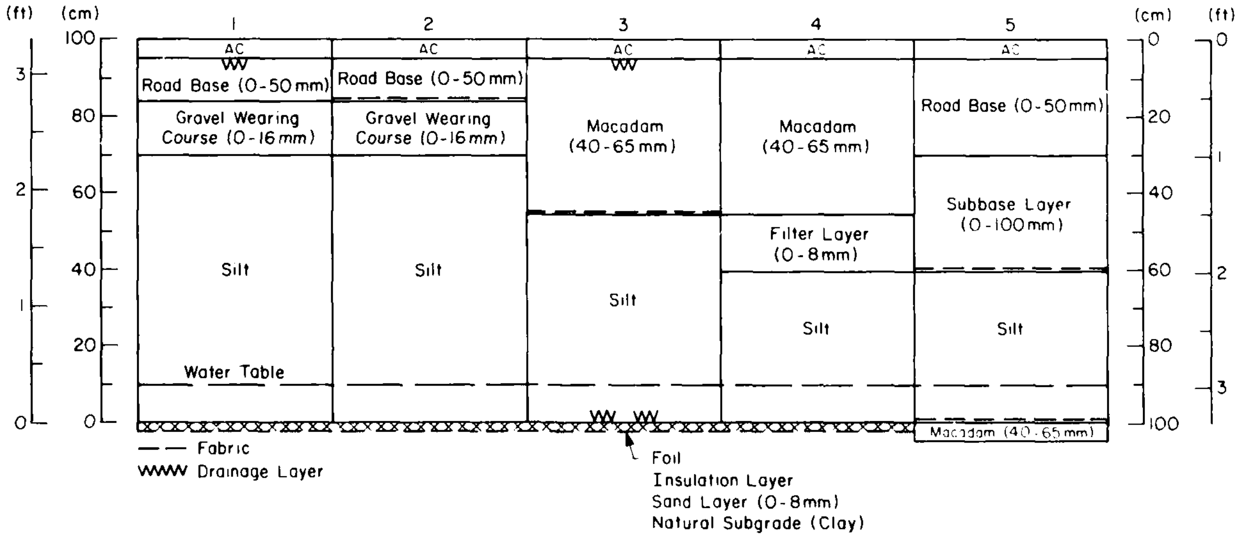


Figure 3. Cross section of pavements tested in Swedish pilot field study (after Andersson and Freden 1977) (1 in.= 2.54 mm).

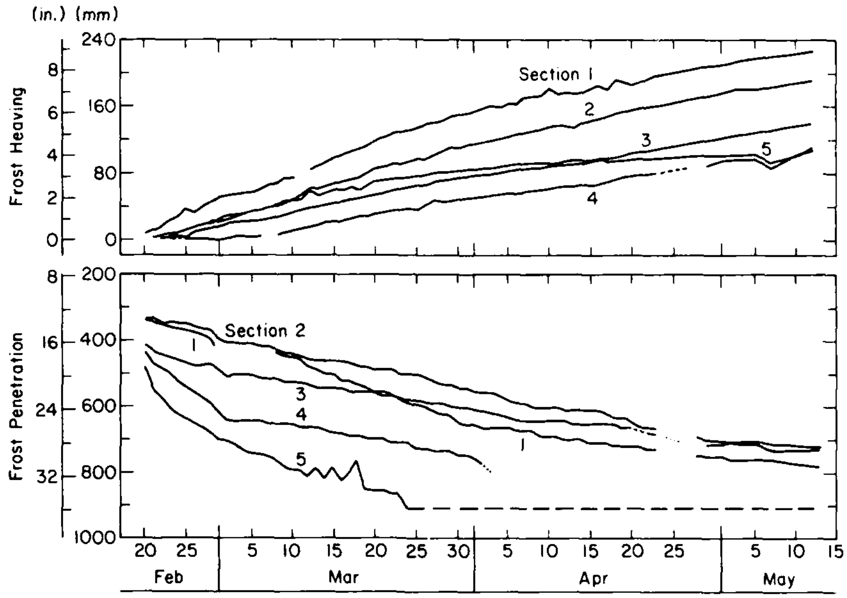


Figure 4. Frost heave and frost penetration of pavements tested in Swedish pilot field study (after Andersson and Freden 1977). See Figure 3 for descriptions of each section.

Andersson and Freden's objective was to compare the frost heave and thaw weakening of the various test sections. Frost heave results are presented in Figure 4. These results show that, in a section where a geotextile was placed between the base course of the new pavement and the wearing course of an old gravel road, frost heave was greatly reduced compared to the section without fabric (sections 1 and 2). The purpose of emplacing the fabric was to strengthen the pavement section and frost penetrated this layer within 5 days. The lifetime of the geotextile-reinforced section increased considerably—over twice as many load applications during the thaw season were required to cause failure. Test sections 3 and 4 compared a typical filter layer consisting of clean sand and using a geotextile for the same purpose. The sand layer resisted heave better than the fabric did, although the silt layer was 15 cm thinner in this section. Unfortunately, no specific information regarding the fabric is provided so that properties of the sand layer and the geotextile could not be compared.

Summary

Since many geotextiles have hydraulic conductivities similar to those for clean, medium to fine sand, and have less of an affinity for water than soils, they are candidates for use as capillary breaks in frost heaving soils. The surface properties of geotextile fibers, which are currently not well quantified, will influence the wetting angle of the fibers and whether a fabric will attract fine soil particles. Of the two most commonly used polymers, polypropylene and polyethylene, polypropylene is more hydrophobic.

In addition to hydraulic conductivity and surface properties, physical properties of geotextiles important for consideration in capillary break behavior include resistance to clogging and blinding, threshold pressure and separating ability.

Of the three common methods of constructing nonwoven fabrics, needle punching results in the most permeable, resin bonding results in the least permeable and heat bonding results in intermediately permeable fabrics. Based on surface and hydraulic properties, as well as cost, needle-punched and heat-bonded polypropylene fabrics are good candidates for capillary breaks.

Laboratory studies reported by Allen et al. (1983) indicate that the frost heave rate was significantly reduced (up to 85%) by using relatively hydrophobic fabrics (needle-punched and heat-bonded polypropylene geotextiles). Ponding of water above the fabrics, however, may be a problem when very hydrophobic materials are used. Other work determined that a capillary break was most effective when placed between the water table and the greatest depth of frost, and that soil *reinforcement* by geotextiles probably helped reduce frost heave.

Chamberlain* found significant reduction in laboratory frost heave rates using a needle-punched polypropylene geotextile as a capillary break. He also found that the needle-punched polypropylene fabric reduced heave in sandy soil more than a woven fabric of lesser permeability did. Furthermore, doubling the thickness of the needle-punched fabric apparently doubled the reduction in frost heave.

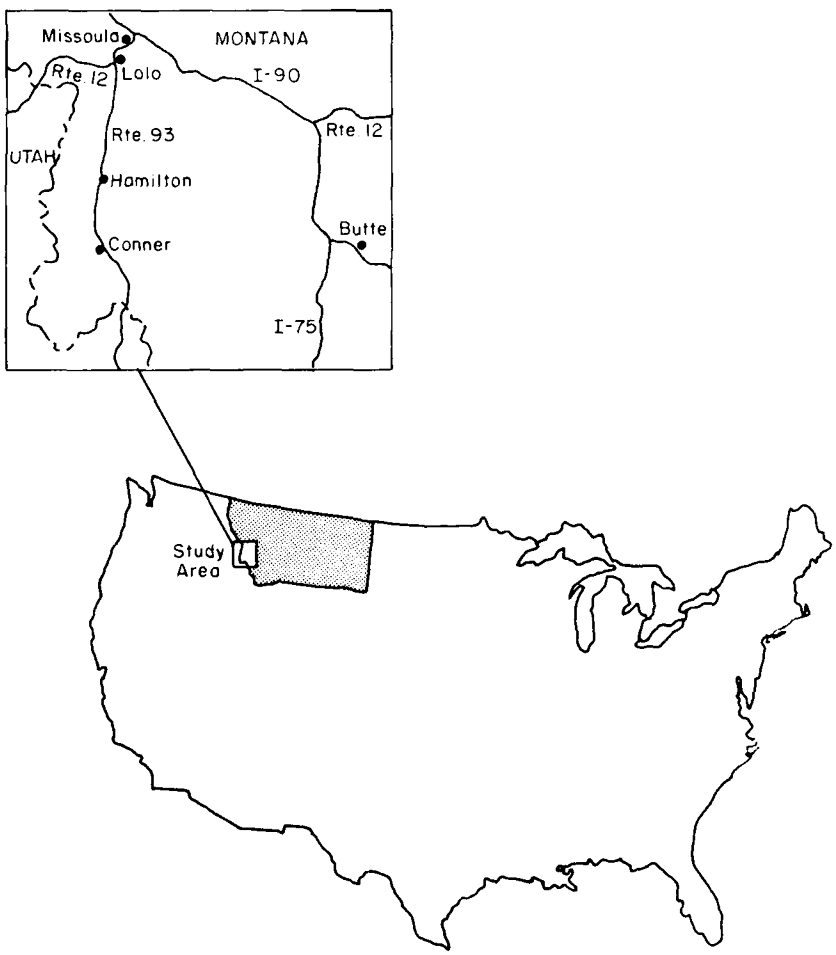
One field study revealed that a geotextile reduced heave when placed between the wearing course of an old gravel road and new pavement by reinforcing the pavement section. Another study showed that fabric use with a granular base or with non-frost-susceptible subgrades does not appear to be worthwhile.

*Personal communication with E. Chamberlain, CRREL, 1986.

EXPERIMENTAL RESULTS AND ANALYSIS

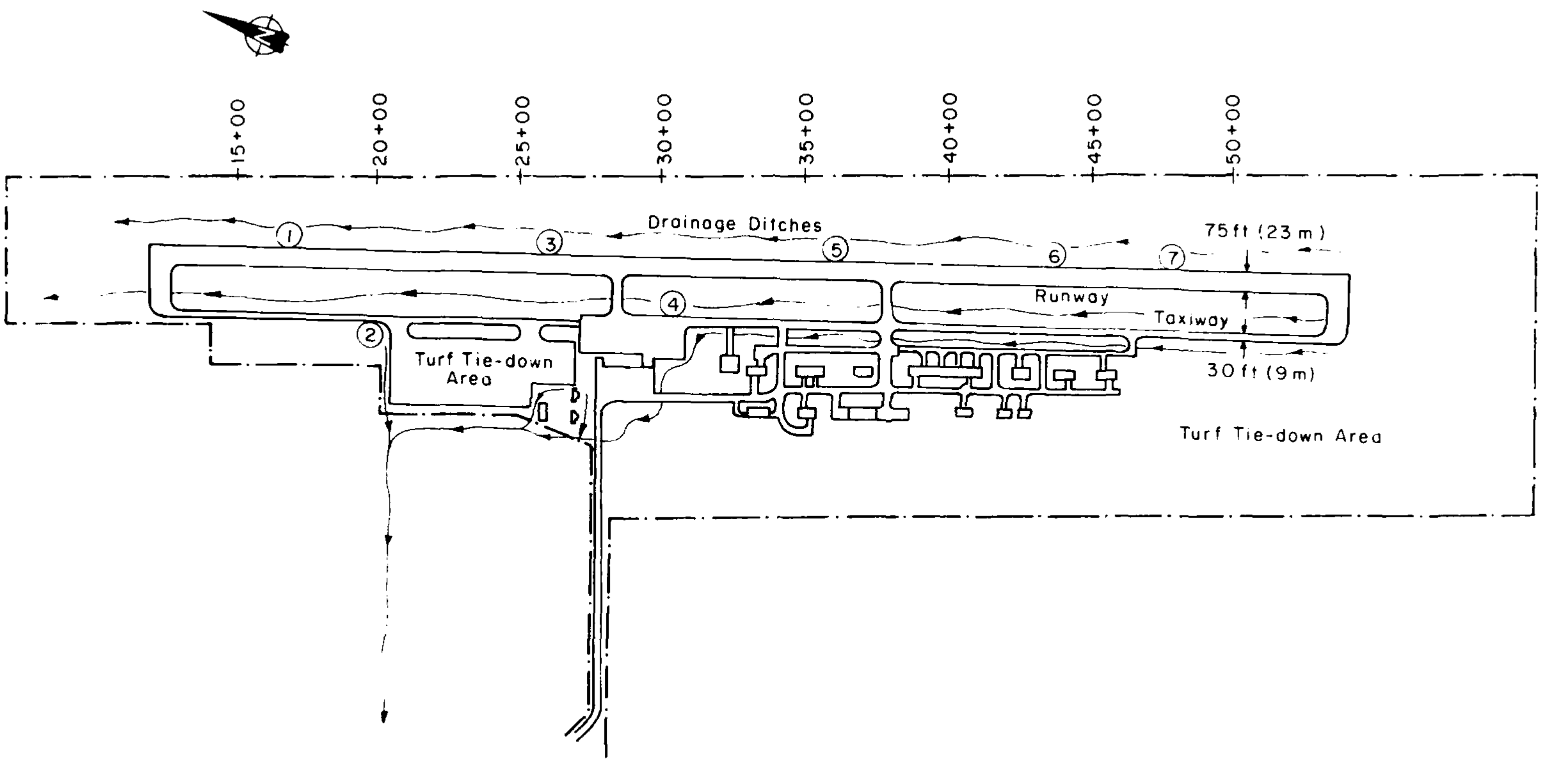
There were two main objectives of the laboratory testing program. The first was to assess the ability of geotextiles to mitigate frost heave by placing fabrics in frost-susceptible soils and then freezing them in a standard frost heave test. Second, the frost-susceptibilities and hydraulic properties of in-situ soils at Ravalli County Airport were determined to aid in the analysis of the field data presented in a companion report (Henry 1990). Experimental results are contained in an Internal Report that can be obtained by contacting CRREL (Henry 1987).

During a site investigation conducted in August 1985, soils were collected from two locations at the Ravalli County Airport—survey station 43+50



a. Location map.

Figure 5. Ravalli County Airport in Hamilton, Montana.



b. Site map showing sampling stations.

Figure 5 (cont'd). Ravalli County Airport in Hamilton, Montana.

(monitoring station 6) and survey station 26+00 (monitoring station 3) (Fig. 5). The samples were sent to CRREL for determination of grain size distributions, soil moisture characteristics, unsaturated hydraulic conductivities and frost-susceptibility. Boring logs recorded at that time and grain size distribution curves determined by an independent soils lab (GMT Inc.) and at CRREL are presented in a companion report (Henry 1990).

In addition to the tests mentioned above, two types of geotextiles were inserted into various frost heave samples and frozen in standard frost heave tests to evaluate their ability to reduce frost heave. Table 5 contains a summary of tests conducted on soils collected at the airport. An attempt was also made to characterize the hydraulic properties of one of the geotextiles used by conducting soil moisture retention and hydraulic conductivity tests on the fabric.

This section presents the details, results and analyses of the experimental work conducted on the soil samples collected at Ravalli County Airport.

Table 5. Laboratory tests conducted on soils collected from Ravalli County Airport.

Sample depth and soil type	*Soil moisture retention*	*Unsaturated hydraulic conductivity*	*Frost susceptibility*	*Use of geotextile to reduce heave*
		Station 3		
6–61 cm (0.2–2.0 ft) GM			X	
79–146 cm (2.6–4.8 ft) ML			X	
		Station 6		
5–15 cm (0.17–0.5 ft) SM				
15–30.5 cm (0.5–1.0 ft) SM	X	X	X	X
44–61 cm (1.6–2.0 ft) ML	X	X	X	
82 cm (2.7 ft) ML	X	X	X	X

Soil moisture characteristic and unsaturated hydraulic conductivity

Experimental procedure

Soil moisture retention and unsaturated hydraulic conductivity values were experimentally measured with a pressure cell permeameter, designed and constructed at CRREL (Ingersoll 1981). These data were used primarily for support of the field study described in Henry (1990). Therefore, the results of these tests are presented but not discussed in any detail here.

The pressure cell permeameter is similar to a device described by Klute (1965) for measurement of unsaturated hydraulic conductivity, although Ingersoll (1981) modified it to be used for determining moisture characteristic curves as well.

For moisture retention determination, positive air pressure is applied to the soil through side ports in the sample container to force water from the pores. Water flows out of porous plates at the top and bottom until equilibrium is reached (i.e., until water flow ceases); the water content is then determined based on how much water was released.

Hydraulic conductivities were determined at the various water contents by maintaining the appropriate soil water pressure after the soil moisture retention had been determined, and measuring the rate of flow of water through the sample under a constant head. The test procedure is discussed in detail in the following section.

Equipment. The pressure cell permeameter is shown in Figure 6. The soil sample was contained in a clear plastic cylinder with a 7.62-cm (3.0-in.) inner diameter and a length of 7.95 cm (3.13 in.). The end caps contained porous stones. The end cap assembly is the same as that for Tempe cells (Soil Moisture Equipment Corp., undated). The end caps contained connections for water to flow into or drain from the soil specimen as shown in Figure 6.

Manometers were permanently affixed to the cylinder in a vertical line with a spacing of 4 cm (1.6 in.), centered along the length of the cylinder. The manometers measured the soil water pressures to establish the hydraulic gradient. Tensiometers were modified by attaching pressure transducers (linear) in place of vacuum dials to the reservoirs of the tensiometers. The transducers were powered by a 10-V dc power source.

Air pressure was applied to the sample through 12 small holes, about 0.8 mm (0.03 in.)

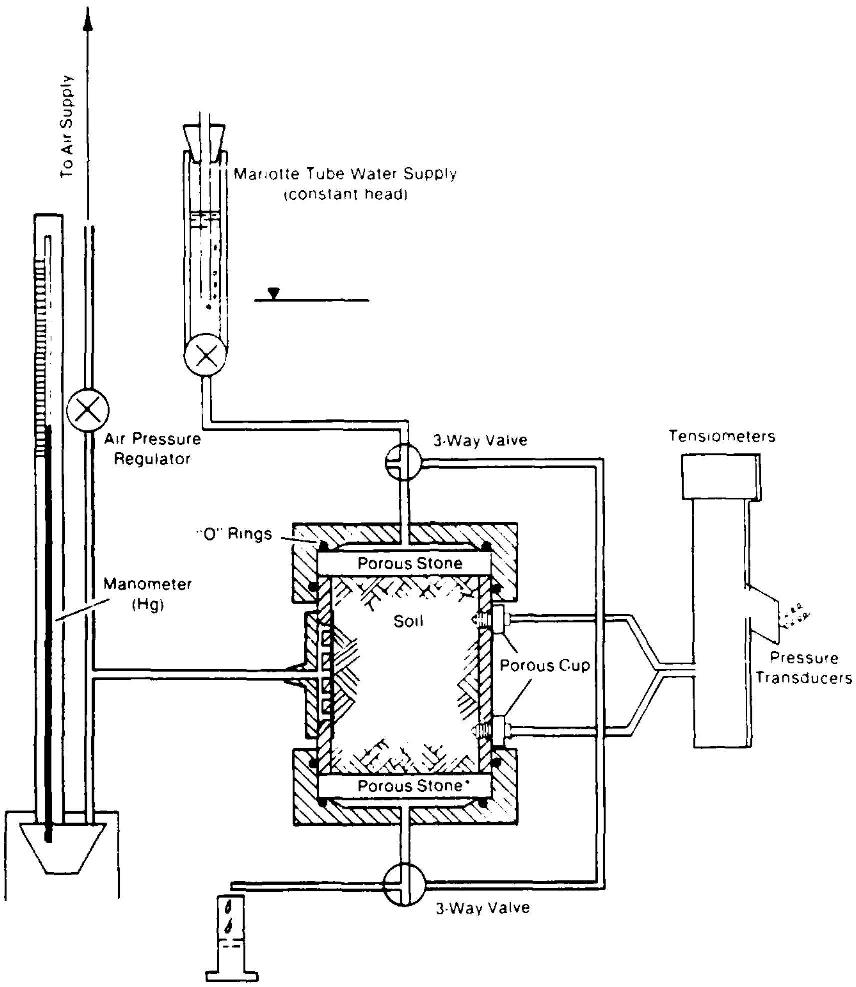


Figure 6. Pressure cell permeameter (after Ingersoll 1981).

in diameter, drilled in a grid pattern extending halfway around the cell. Grooves were etched into the cylinder wall between the holes to d sperse air from the pressure source into the soil. A cylinder segment having the same inside diameter as the outer diameter of the soil container covered the grid pattern; this segment was sealed around the edges with epoxy. Pressurized air was applied to the sample through a connector in the outer plastic segment.

Tubes with three-way valves were connected to the top and bottom end caps. This allowed drainage from both ends of the specimen during extraction when pressure was applied. Water was collected in a graduated cylinder at the bottom of the sample. A Mariotte tube (constant head) water supply was provided at the top of the specimen for separate hydraulic conductivity determinations.

The assembly used for soil testing was also used for the testing of Fibertex 400. Determinations were made on 27 layers of material stacked up in a regular soil sample cell just described.

Sample preparation. After grain size distribution was determined, the air-dried soil was reconstituted by remixing and adding distilled water until the field water content was obtained. During reconstitution, large stones (over 1.9 cm or 0.75 in.) were removed and replaced by an equal weight of material ranging from 1.27 to 1.9 cm (0.5 to 0.75 in.) in diameter. The soil was then placed in the sample cylinder in five layers, each layer being tamped in place and then scarified with a fork to improve continuity. The sample was compacted to a specified density, usually field density or greater. Care was taken not to damage the porous cups of the tensiometers while assuring that the full surface area of the porous cups was in contact with the soil. Once the soil was in place, the wet and dry densities were calculated.

The porous stones and end caps were placed on the cylinder and the entire assembly was placed in a vacuum jar under a vacuum for 4 to 8 hours. The jar was then filled with distilled, deaired water while the vacuum was still being applied and the sample was allowed to saturate overnight under these conditions.

After saturation was complete, the specimen was removed and weighed. The weight of the entire saturated assembly was used to test for leaks because any weight loss during testing would be ascribable to loss of water. The cell was then connected to the test assembly. All ports, valves and tubing were filled with water using a syringe to ensure that no air remained in the system.

After the system was completely assembled as shown in Figure 6, the manometers were calibrated. The manometers were first zeroed, then a known vacuum applied and millivolt readout recorded (e.g., 0.001 V = 500 Pa or 2.0 in. of water). Except for compaction of the specimen, this same procedure was used for preparation of the hydraulic tests on the geotextile.

Test procedure. The first test run on the soil was a constant-head, saturated hydraulic conductivity test. The three-way valves were set to allow flow from the Mariotte tube through the sample and into the collecting flask. The gradient in pore water pressure was measured by the manometers and the hydraulic conductivity was calculated as follows

$$k = QL/dAt \tag{4}$$

where k = hydraulic conductivity (cm/s)
Q = quantity of water that flowed through the sample (cm^3)
A = sample cross-sectional area (cm^2)
L = distance between manometers (cm)
d = head loss between manometers (cm of water)
t = time (s).

Three determinations of saturated hydraulic conductivity were made per sample and an average value was taken. In all tests the measured values of saturated hydraulic conductivities were within ±90% of the average value.

At this point the three-way valves were turned so that the water supply was cut off, and water could exit the sample at the top and bottom and discharge to the collecting tube. The first extraction pressure increment was applied to the sample, and all the water expelled was collected. It was assumed that equilibrium was reached when the flow had stopped and when there was no pressure gradient between the manometers. The quantity of water expelled was recorded for determination of water content.

While the sample was still under pressure, hydraulic conductivity was determined. The three-way valves were set to allow water flow through the specimen. The air pressure within the cell kept the larger pores from filling with water. Volumes of water flowing into and out of the specimen were monitored until they became equal; the length of time for this to happen increased with higher extraction pressures. Early hydraulic conductivity tests took about 1 day to complete, while the later tests took up to 4 days. One or two hydraulic conductivity determinations were made at each extraction pressure.

Once an extraction pressure of 70 kPa (10.2 lb/in.^{2}) was reached, the sample was allowed to resaturate in steps as the pressure was decreased. The only modification made for this procedure was that the water table was lowered to the top of the sample, allowing sorption curves for soil moisture retention to be determined.

Soil moisture retention and unsaturated hydraulic conductivity determinations were made on 27 layers of Fibertex 400 stacked in a standard sample cell (previously described) according to the procedure just described. Saturated hydraulic conductivity had to be determined in a separate falling head test because the large flow volume and velocity produced with the constant head procedure made accurate measurements impossible. The head difference in the falling head test was 1 cm (0.4 in.).

Hydraulic characteristic results

Moisture retention results for station 6 soils are presented in Figure 7. Figure 8 shows unsaturated hydraulic conductivities as a function of soil moisture tension. Only the silt collected from 82 cm (2.7 ft) shows hysteresis in the moisture retention curves. Note that even though the initial hydraulic conductivity of the silty soil (collected at 82 cm or 2.7 ft) is lower than the other soils by an order of magnitude, at tensions as low as 5 kPa (0.7 lb/in.^{2}), the hydraulic conductivity of the silt has not changed significantly, but the hydraulic conductivities of the coarse-grained soils have dropped to values lower than those of the silt.

The densities of the samples tested were very close to the field densities reported, with the exception of the silt, which was 10% more dense for the laboratory test.

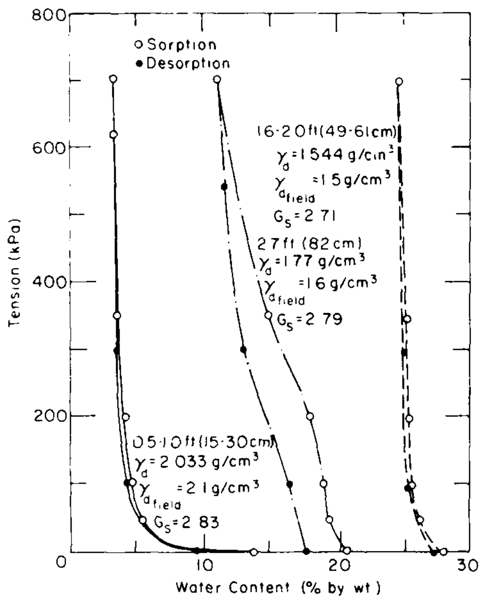


Figure 7. Soil moisture characteristic curves, monitoring station 6, Ravalli County Airport.

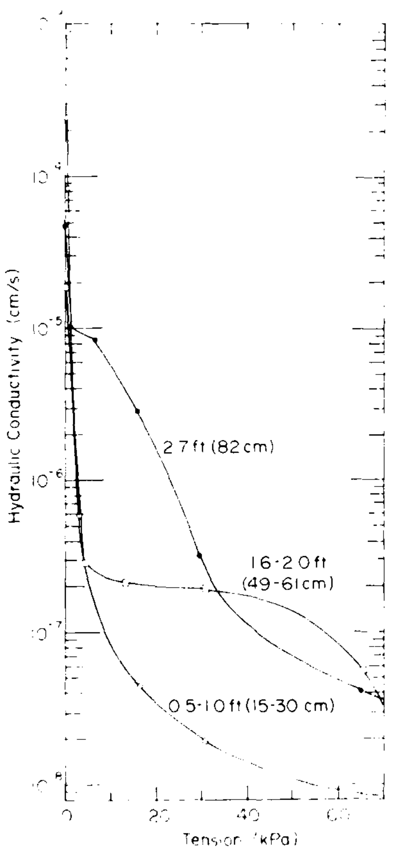


Figure 8. Unsaturated hydraulic conductivity curves, monitoring station 6, Ravalli County Airport.

Figure 9 shows the results of the soil moisture retention and hydraulic conductivity determinations on Fibertex 400. Note that the saturated hydraulic conductivity is different by a half order of magnitude from that published by the manufacturer (Table 6).

The hydrophobicity of Fibertex (compared to soil) was apparent throughout these experiments. At an extraction pressure of 8.9 kPa (1.3 lb/in.^{2}), during the hydraulic conductivity determination, the fabric was so dry that no moisture was in contact with the porous cups to give pressure readings and the test was ended. When the fabric was removed from the soil, it felt dry to the touch.

Results from hydraulic tests will be discussed in analyses presented later in this report.

Laboratory frost heave tests

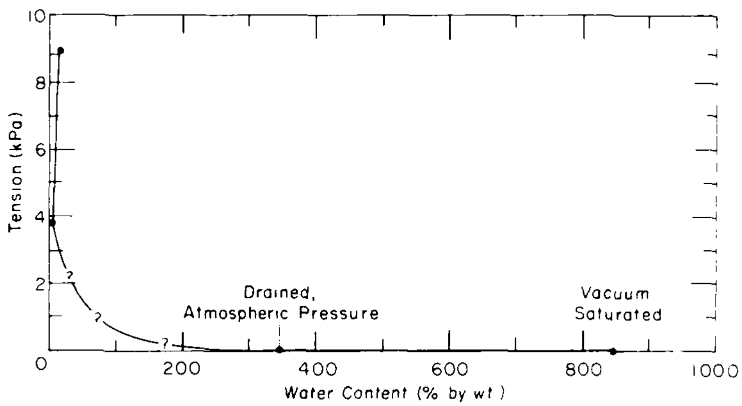
Experimental procedure

Equipment. The frost heave tests were run in the CRREL soils laboratory in a small, chest-type freezer especially adapted for this test (Chamberlain and Carbee 1981). The freezer was divided into two sections—one 56 × 56 × 56 cm (22 × 22 × 22 in.) in which four soil freezing tests were conducted simultaneously, and the other 30.5 × 56 × 84 cm (12 × 22 × 33 in.), containing an ice bath for thermocouple calibration and heating and cooling equipment for ambient temperature control. The sections were divided by a piece of Styrofoam insulation to prevent excessive convection in the freezing chamber.

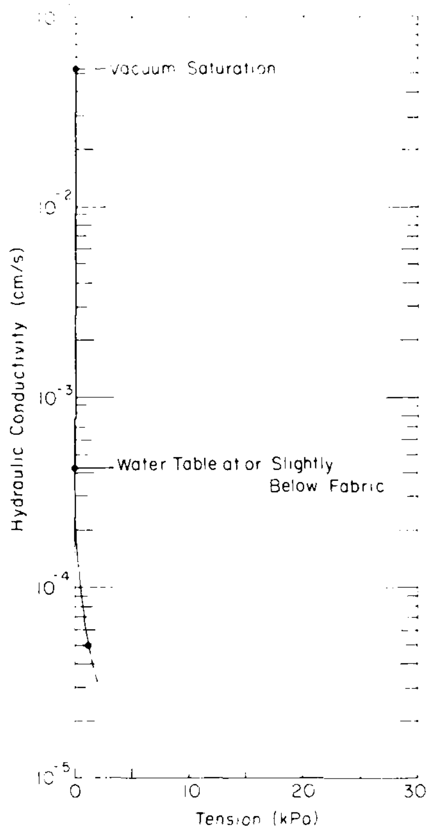
Cooling fans circulated air around a 2.5-cm (1-in.) space between the freezer chest wall and Styrofoam insulation on the outside of the freezing chamber to maintain a constant temperature. Acrylic sheets were placed over the top of the entire freezer to minimize heat loss when the experiment was being observed.

The freezer's factory thermostat and temperature control system were removed and replaced by a manually adjustable temperature control, operable from the exterior. The ice bath for thermocouple calibration consisted of a vacuum bottle full of ice water stoppered by a rubber cork through which thermocouple wire could be inserted.

The soil specimens were contained in tapered Plexiglas cells, 15.2 cm (6 in.) in length with a 14.0-cm (5.5-in.) inner diameter on the bottom and a 14.6-cm (5.75-in.) inner diameter on the top. The purpose of the taper was to minimize side friction during heave. The sample rested on a porous stone



a. Soil moisture characteristic curve.



b. Unsaturated hydraulic conductivity.

Figure 9. Test results on Fibertex 400.

Table 6. Properties of geotextiles, as published by the manufacturers, used in laboratory frost heave experiments.

Geotextile	Manufacturer/ distributor	Weight (oz/yd^2)	Weight (kg/m^2)	Thickness (mils)	Thickness (cm)	Hydraulic cond (cm/s)	Equivalent opening size (US standard) (sieve no.)	Equivalent opening size (US standard) (mm)	Cost $(\$/yd^2)$	Cost $(\$/m^2)$	Burst Strength $(lb/in.^2)$	Burst Strength (kPa)
Fibertex 400	Crown Zellerbach	12.0	0.407	150	0.381	0.3	100+	0.15+	1.40	1.17	450	3102
Typar 3401	Dupont	4.0	0.136	15	0.038	0.03	70–100	0.23–0.15	0.60	0.50	200	1379

and was enclosed by a plastic end cap on the bottom (Fig. 10). There was a filter between the soil and the porous stone to prevent particle migration into the stone. The bottom end cap had two holes drilled in it. A hose was attached to one for a water supply to the base of the sample. The other hole was connected to a hose that was routed through the bottom of the freezer and attached vertically to the side. This allowed the water level to be monitored and the samples to be purged of air when needed. Water was provided to the base plate from Mariotte tubes, which were connected to the supply side port in the bottom base plate through a hole to the outside of the freezer.

Throughout the test, the samples were in contact with aluminum heat transfer base plates (warm plates), kept at a constant temperature by electronically controlled glycol temperature baths. A top heat transfer plate (cold plate) was in contact with plastic wrap that directly covered the soil in each sample. The cold plates were gradually cooled throughout the experiment. The glycol–water

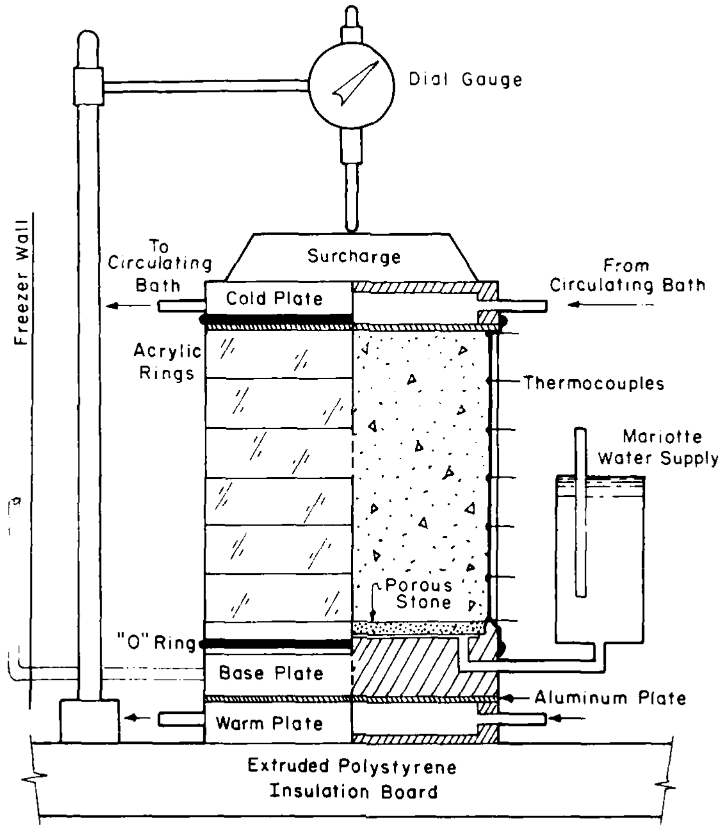


Figure 10. Soil sample assembly for standard CRREL frost heave test (after Chamberlain 1984). The water table was monitored on the exterior of the freezer.

mixture connected to the cooling plates ran from plate to plate in a series configuration. The temperatures of the glycol baths could be controlled manually or automatically at the cooling units.

Eight vertically aligned thermocouples with equal spacing were inserted into the soil through small holes (2-mm or 0.08-in. diameter) drilled into the cylinder. The topmost thermocouple was in direct contact with the soil and plate. The thermocouples were fed directly into a Hewlett Packard HP3421A data acquisition and control unit.

A 3.5-kPa (0.5-lb/in.^{2}) surcharge was placed on top of the upper cold plate to simulate the weight of 15 cm (6 in.) of pavement and base. A dial gauge and a Direct Current Differential Transformer (DCDT) were placed on the top of the cold plate to record frost heave. The DCDTs were also joined to the data and acquisition control unit.

A schematic of the data acquisition and control system is shown in Figure 11 (Chamberlain 1984). The system utilizes an HP82162A thermal printer and an HP8216A digital cassette drive in addition to a calculator and data logger. Three program series provided the necessary control for this test. Since all three series could not be stored in the HP41CX memory, they were stored on a tape cassette in the HP3216A cassette drive and recalled as needed (Chamberlain 1984).

The first program series calibrated and stored the thermocouple 0°C (32°F) temperature shifts, allowed adjustment of the set point bath temperatures, calibrated starting positions of the DCDTs and initialized the data tape cassette with project name and storage space (Chamberlain 1984). The second program series controlled temperature, data logging and reduction, printing and data storage. The third program series plotted stored data after the frost heave test was completed.

Sample preparation. The soil used for grain size analyses was reconstituted to field density and moisture content. Distilled water was used in reconstitution of the samples. It is currently thought that this results in a fairly accurate simulation of field soil water conditions because, during drying of the soil, only pure water evaporates, leaving the chemical impurities in the water on the soil par-

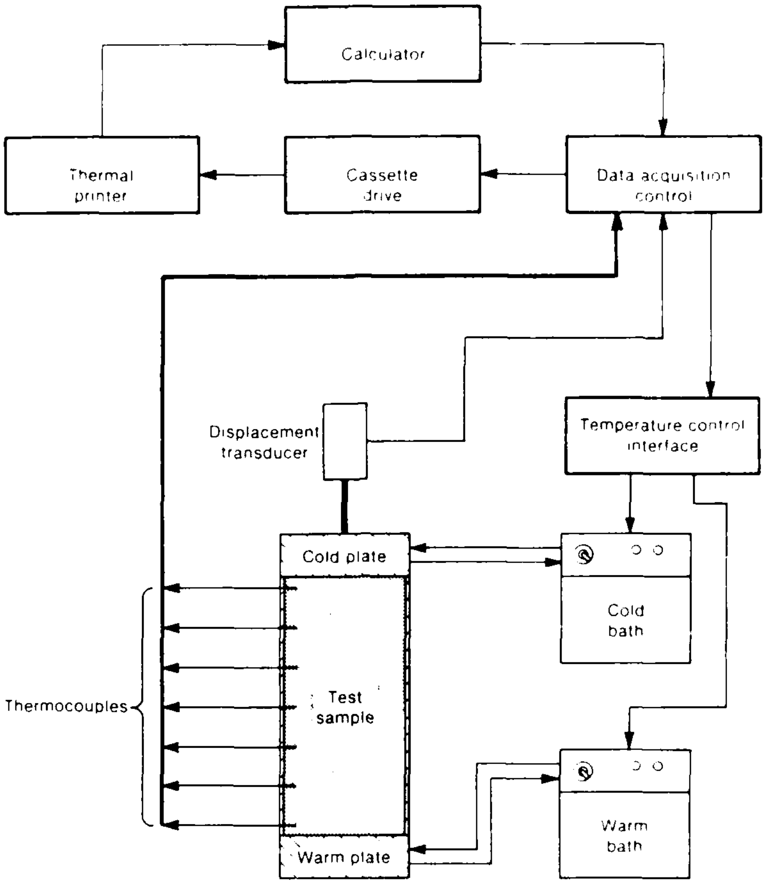


Figure 11. Schematic of automated data acquisition and control system for CRREL frost heave test (from Chamberlain 1984).

ticles. When the soil is rehydrated with distilled water, it is assumed that the soil water resumes its original chemistry. This approach assumes that none of the chemicals present in the original water attach permanently to soil particles when drying occurs and that no chemicals evaporate. No testing of effects of using the original soil pore water vs distilled water throughout the CRREL frost heave test has been done.*

Soil was placed into the frost heave mold in one of two ways. In the first method, soil was compacted uniformly into a tapered proctor mold of the same dimensions as the frost heave mold. Five layers were emplaced, each being compacted by dropping a 2.2-kg (10-lb) weight through a distance of 46 cm (1.5 ft) 55 times. Each layer was scarified after compaction to help achieve uniformity. After the sample was compacted, the collar of the mold was removed and the top of the sample trimmed. The soil was then transferred to the frost heave mold. This procedure worked well and was used for the coarser soils tested.

The second method of sample compaction was used for all silt samples. The silts' field densities were too low and the water contents too high for the sample to be transferred from the compaction mold to the frost heave mold without slumping. For this reason, silts were placed directly into the frost heave mold, but not compacted the same way as the coarser soils. This was appropriate because of the very high water content of the soil. Care was taken not to damage the frost heave mold with the drop hammer during this process. The reason that the coarser soils weren't compacted in this manner was fear that stones might crack the Plexiglas cell when hit with the hammer.

The above sample preparation technique was modified for preparing soil samples containing geotextile fabric. The first two layers of soil were compacted in a proctor mold, then transferred to a frost heave mold. The edge of a circular sample of

*Personal communication with E. Chamberlain, CRREL, 1986.

geotextile was then covered with silicone cement and placed carefully in the frost heave mold on top of the soil. The samples were allowed to stand for about 30 minutes to ensure that the silicone cement would set; the remaining three layers of soil were then added.

Once the soils were in the sample molds, they were placed on top of the warm plates in the freezing cabinet. Thermocouple wires were installed and sealed with silicone cement to prevent leaking. The base plates were connected to the distilled water supply.

Samples were saturated in two stages. The Mariotte tubes were first adjusted to raise the water level halfway up the specimen. The water level remained at this height for 2 to 4 hours, during which time the samples were checked for leaks and repaired with silicone cement if necessary. After this, the water level was raised to the full height of the specimen and samples were allowed to saturate overnight. Again, any leaks were repaired. During the saturation period, the ambient temperature was lowered to 1 to 2°C in preparation for the test. Just prior to the test, the water level was lowered to 1 cm (0.4 in.) above the base plate of the sample. Cork insulation was filled in around the samples, the Plexiglas covering was placed over the top of the freezer, and all dial gauges were set to zero.

At the beginning of the test, the temperature baths were manually set to −4°C (25°F) for the top plate and 1°C (34°F) for the bottom plate. The computer program for the data acquisition was initialized and a data scanning interval was chosen. The computer program calibrated the thermocouples. It did this by reading the temperatures of the thermocouples and referencing them to thermocouple readings in the ice bath.

Once the thermocouples were calibrated, automatic scans of the data began. Scans could also be asked for at any time from the calculator keyboard. An example of an early data printout is shown in Figure 12. When the 0°C (32°F) isotherm showed some penetration into the soil specimen, the top plate was given a sharp rap to initiate ice nucleation.

At the beginning of the test, the cold plate temperature was adjusted manually. When frost penetration stabilized, this temperature was switched to an automatic ramp temperature controller and gradually decreased at a constant rate throughout the test to achieve a constant rate of frost penetration of abut 1.27 cm/day (0.5 in./day). The warm plate temperature was left constant at 1°C.

The test continued until all or most of the samples were completely frozen. At the end of the test,

STANDARD FREEZING TEST

Series Name: HENRY1

TIME: 00:28:03
DATE: 86:07:18
ELAPSED TIME (Hrs) 144.011

TOP BATH TEMP.(deg C) - -2.67
BOT BATH TEMP.(deg C) - 1.15
AMBIENT TEMP.(deg C) - .08
ICE BATH TEMP.(deg C) - .08
INPUT VOLTAGE (dcv) - .0146

	TEMPERATURE (deg C)			
DEPTH (mm)	43+50-1	43+50-2	43+50-3	43+50-4
0.00	-2.53	-2.26	-1.87	-1.40
12.70	-1.81	-1.52	-.92	.21
38.10	-1.41	-1.24	-.37	.49
63.50	-.91	-.90	.16	.88
88.90	-.67	-.51	.54	1.03
114.30	-.07	-.18	.85	1.19
138.70	.05	.11	1.06	1.35
152.40	.15	.49	1.00	1.32
FROST DEPTH (mm)	128.81	130.22	55.80	11.01
FROST HEAVE (mm)	-23.80	-24.66	-17.54	-22.80

Figure 12. Data printout from automated system used in CRREL frost heave test.

samples were removed from the freezer, immediately transported to a coldroom maintained at −7°C (20°F), cut in half lengthwise with a band saw (in the coldroom) and photographed. Half of the sample was saved and the other half was divided into six equal parts for water content determinations and soil water conductivity measurements for calculation of freezing points.

Frost heave results and analyses

Fibertex 400 and Typar 3401 were the geotextiles used in the laboratory experiments. Allen et al. (1983) had found that Fibertex 300 and Typar 3401 reduced the rates of frost heave in laboratory specimens more than other geotextiles tested did. Additionally, Chamberlain* also found that Fibertex 400 reduced frost heave by about 50% in the Standard CRREL Frost Heave Test. Fibertex 400 and Fi-

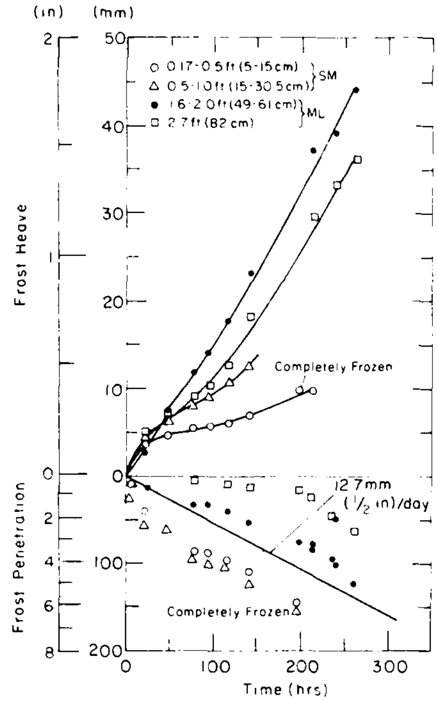
*Personal communication with E. Chamberlain, CRREL, 1986.

bertex 300 are listed as having the same hydraulic conductivity, only 300 is three-quarters the thickness of 400.) Allen et al. (1983) attributed part of the success of Typar 3401 in reducing frost heave to its having greater hydrophobicity than other fabrics tested.

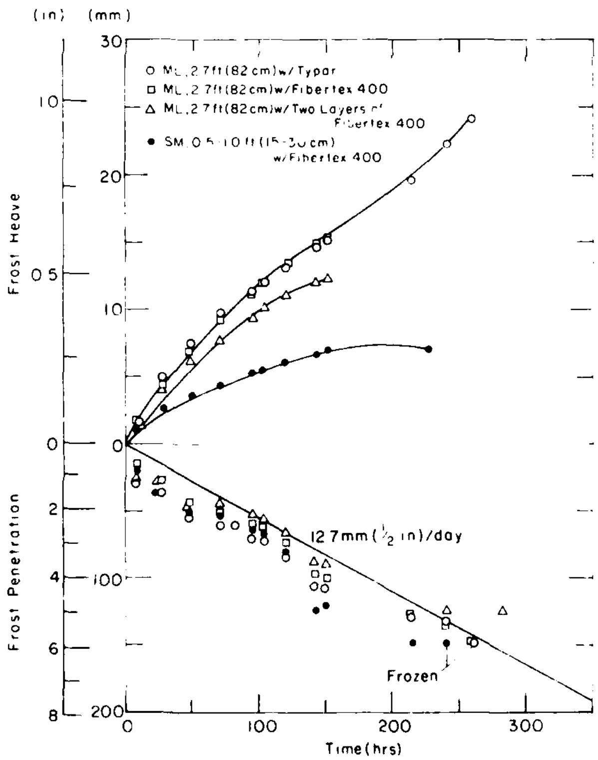
In the present work, Fibertex 400 was tested in silt and silty sand specimens and Typar 3401 was tested in a silt specimen. Both of these fabrics have the same hydraulic conductivity per unit thickness, or permittivity; however, Fibertex 400 is ten times as thick as Typar 3401. (This is not necessarily true when placed in soil, however, as the Fibertex is easily compressed.)

Fibertex 400 is a needle-punched polypropylene geotextile made by Crown Zellerbach and Typar 3401 is a heat-bonded polypropylene fabric made by Dupont, Inc. Table 6 presents the engineering properties of both.

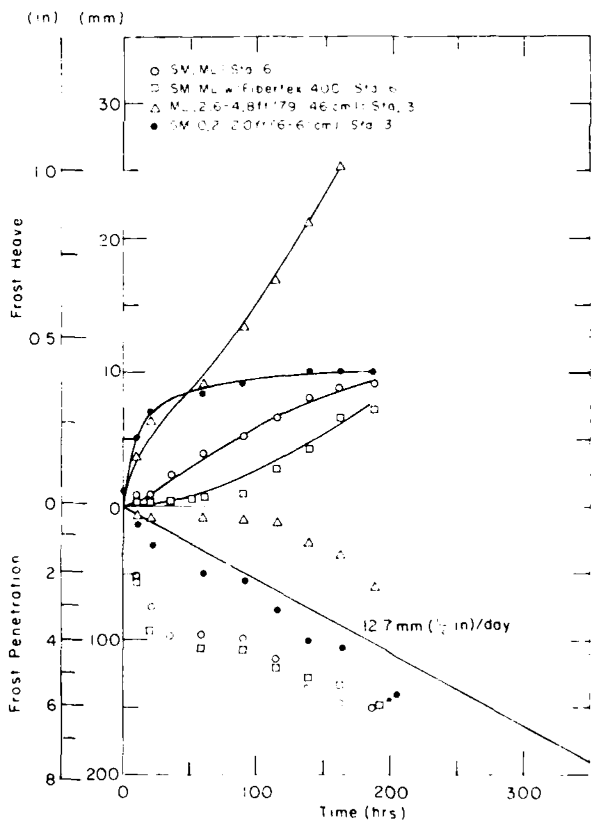
Three main frost heave test series were run; four samples were tested in each series. Results of all three test series, showing frost heave and penetration, are presented in Figure 13. The first test series, represented in Figure 13a, was a standard frost heave test on samples collected from monitoring



a. Test series 1—standard tests on silt from monitoring station 6, no fabric.



b. Test series 2—fabrics were inserted at mid-height in samples.



c. Test series 3—mixed samples.

Figure 13. Frost heave test results.

station 6 at Ravalli County Airport, a location with a history of large amounts of frost heave (Henry 1990). The silt that had the highest rate of heave and a low heaving silty sand in the first test series were used in subsequent tests with geotextiles.

In the second test series, three samples of the high-heaving silt were tested with geotextiles emplaced at the mid-point of the sample (Fig. 13b). One and two layers of Fibertex 400 were used as well as one layer of Typar 3401. One layer of Fibertex 400 was also emplaced in the less frost-susceptible silty sand specimen.

To better estimate field conditions, the effect of layering soil material in the frost heave molds was also considered in the third test series (Fig. 13c). Two layered samples, each consisting of silty sand on the top half and silt on the bottom half, were tested. One of the samples had Fibertex 400 between the layers. The two remaining frost heave tests were conducted on soils collected from station 3 at Ravalli County Airport for determining frost-susceptibility.

Effect of geotextiles on frost heave. The effect of the use of Fibertex 400 and Typar 3401 on the highly frost-susceptible silt is shown in Figure 14. The presence of one layer of either the Fibertex or Typar reduced heave rate by 40 to 50%. Two layers of Fibertex reduced frost heave by about 50 to 55%, only slightly more than one layer did. The results of the tests with Fibertex appear to be in conflict with the results of Chamberlain* presented in Figure 1,

*Unpublished data from E. Chamberlain, CRREL, 1986.

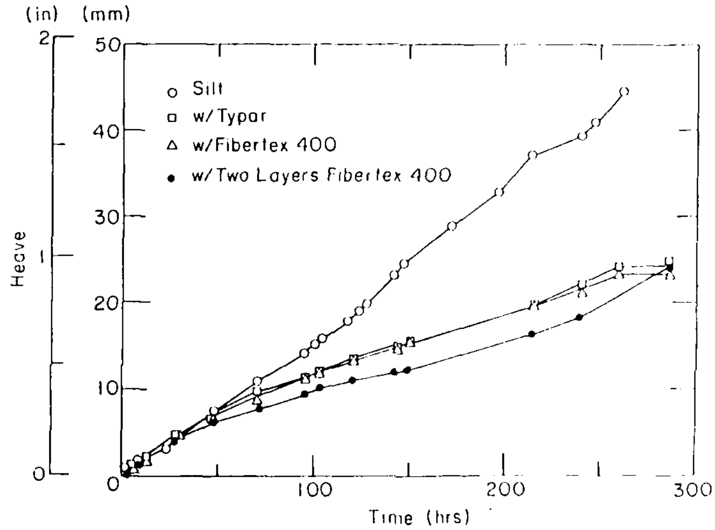


Figure 14. Effect of geotextiles on frost heave of a silt.

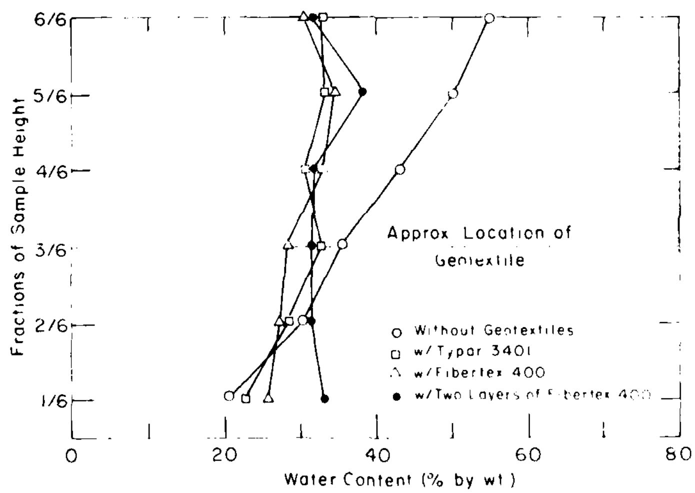


Figure 15. Effect of geotextiles on water content distribution in silty soil from laboratory frost heave test.

which indicate a much greater dependency on fabric thickness. The differences in the two results may be related to a number of factors, including variation in soil type as well as experimental error. As shown in Figure 20, the fabric from the sample with two layers of Fibertex was deformed, probably by ice lens formation. Further research is necessary to obtain more quantitative information about the effect of fabric thickness on frost heave mitigation.

Figure 15 shows the water contents for the same samples after the completion of the tests. Each sample was divided into six slices of equal thicknesses for water content determination. There is no vertical scale on Figure 15 because different samples varied in height because of heave. Below the level of the geotextile, all water contents are roughly equal. In the silt samples containing fabric, average water contents above the fabric layer ranged from 1.2 to 1.3 times the values of saturated water contents, indicating that little water migrated through the geotextile layer and that this was not strongly influenced by type of geotextile. Water contents in the top half of the silt sample frozen without a fabric were found to be almost twice the saturated water content.

The effect of geotextile on the heave of the silty sand (which was used as a base course "gravel" at the Ravalli County Airport) is shown in Figure 16. The geotextile reduced heave by amounts ranging from 40 to 60% throughout the freezing period. Water content distributions in the samples after the tests are shown in Figure 17. The decreased water content at fractions of 4/6 and 5/6 of the specimen height in the sample without fabric were not expected. A possible explanation for the relative water content distributions is that the samples are not identical; this is a random experimental variation.

The results of frost heave tests on layered silty sand samples are presented in Figure 18. The frost line penetrated the soil layer interface very early in this test at about 15 hours for both the reference and the sample containing the fabric. Ideally, the frost penetration should have been much later, at about 100 hours to allow for more optimum frost heave conditions. However, the test results show that the sample with geotextile did heave less than the reference. Water content distributions are shown in Figure 19. This figure does not clearly show that the geotextile reduced water contents above it.

Figure 20 shows the positions of the geotextiles in soil specimens after testing, while the samples were still frozen. The geotextile remained essentially horizontal in the silty sand and layered silty sand–silt samples, but seemed to move considerably in the silt specimens. The concave configurations in Figures 20a and b may be attributable to the method of compaction of the samples; that is, the fabrics were depressed in the center portion by the compactive effort. The most likely explanation for the convexity of the fabric shown in Figure 20c is that an ice lens formed below the fabric. As mentioned earlier, the apparent upward migration of the fabric may be part of the reason why two layers of Fibertex 400 seem only slightly more effective in mitigating frost heave than one layer.

Freezing point determinations (on the same fractions from which water contents were determined) from the first test series indicated that all freezing

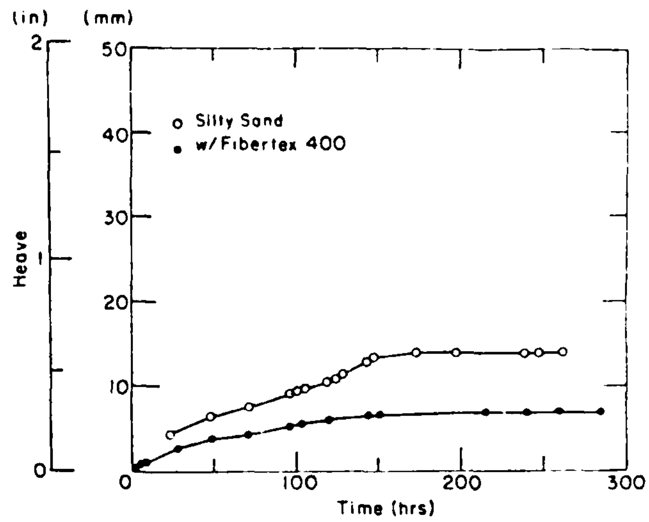


Figure 16. Effect of geotextiles on frost heave of silty sand.

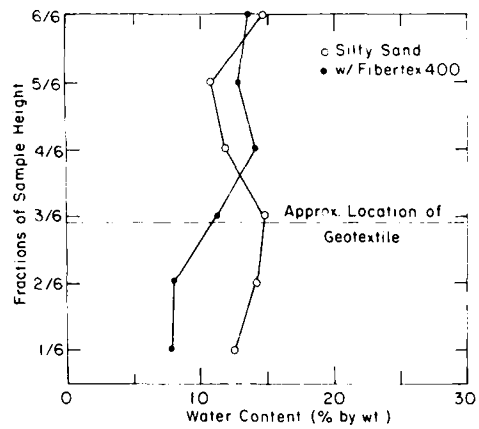


Figure 17. Effect of geotextiles on water content distribution in frost heave test sample of silty sand.

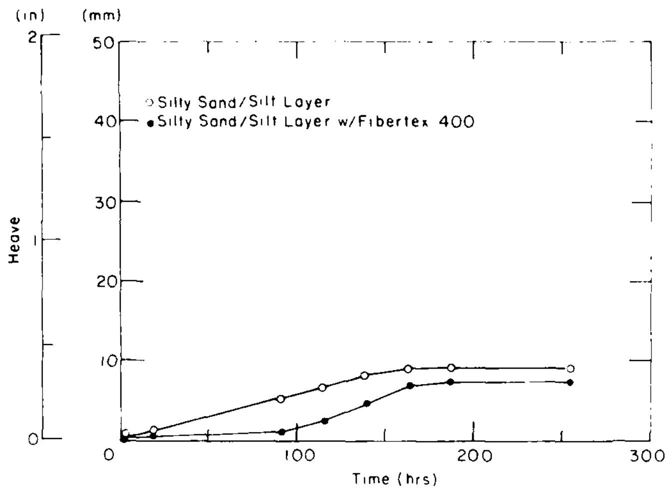


Figure 18. Effect of geotextiles on frost heave of layered silty sand–silt samples.

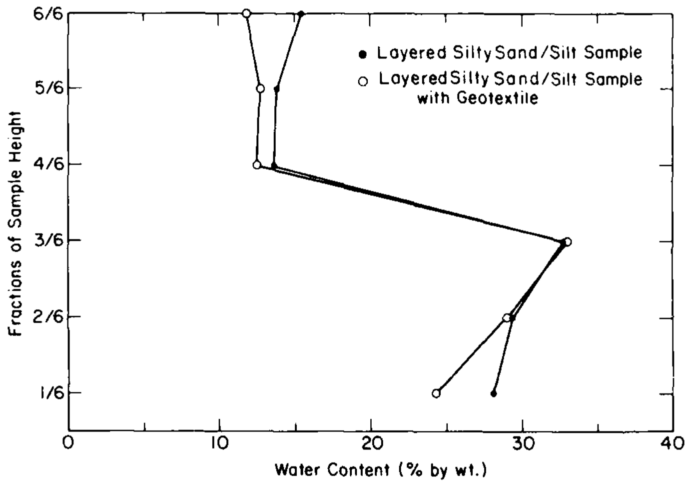
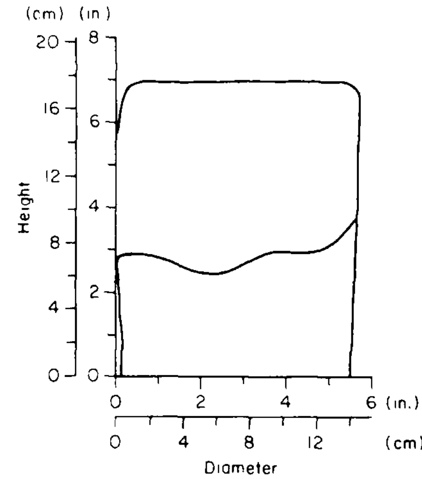


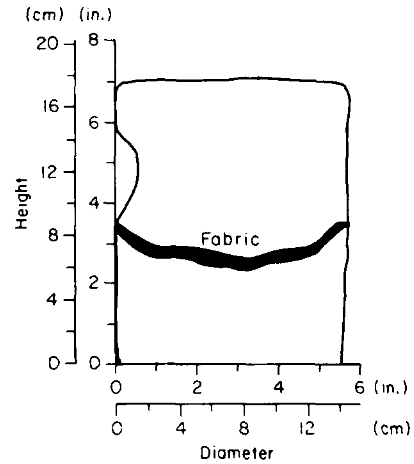
Figure 19. Effect of geotextiles on water content distribution in layered silty sand–silt sample.

points of the soil water were –0.7°C (30.7°F) or higher. Furthermore, no consistent variation of freezing points with location in the sample were noted. This is somewhat surprising as the Ravalli County Airport Soils are described as saline; thus, a depressed freezing point was expected. Error might have been introduced with the present technique of using distilled water throughout the frost heave test or the present drainage at the airport may have allowed considerable leaching of sodium, or both.

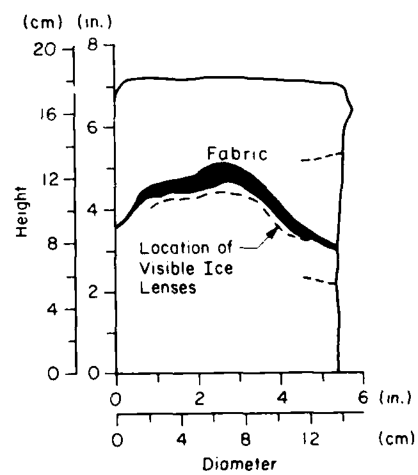
Based on results of the frost heave tests, it appears that Fibertex 400 is capable of reducing frost heave in both silty and gravelly soils as well as in layered silty sand–silt soil. Additionally, Typar 3401 had an almost identical effect in reducing heave of a silt, as did Fibertex 400. The ability of a



a. Typar in silt.

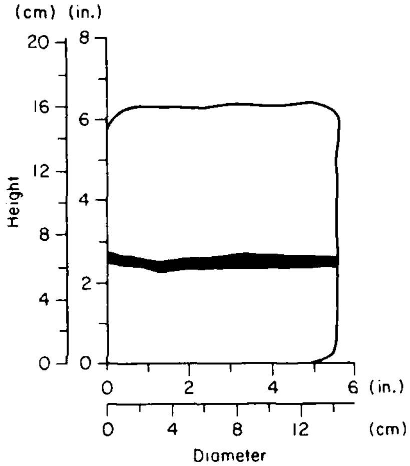


b. Fibertex 400 in silt.

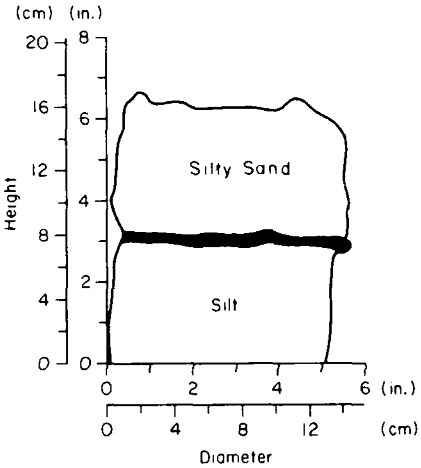


c. Two layers of Fibertex 400 in silt.

Figure 20. Locations of geotextiles in frozen samples at end of frost heave tests.



d. Fibertex 400 in silty sand.



e. Fibertex 400 in silty sand–silt

Figure 20 (cont'd).

geotextile to reduce heave may be due to it being a layer containing relatively large pore sizes, as well as being attributable to the surface properties of the fibers, which would result in the geotextile having a lower affinity for water than soil particles; both factors would contribute to reduced capillarity of the geotextile compared to the soil. Another factor affecting heave rates may be the unsaturated hydraulic conductivity of the geotextile, if it is lower than that of the surrounding soil.

Considering capillarity, the height of capillary rise (h_c) in a tube is

$$h_c = \frac{2\,T_s \cos\alpha}{r\gamma} \tag{5}$$

where T_s = surface tension of liquid
r = radius of the tube
γ = unit weight of the liquid
α = contact angle between the liquid and the tube.

This relationship clarifies the role of surface properties in the capillary behavior of geotextiles. Most geotextiles probably have wetting angles (α) that are different from those of soil particles. Fibers with wetting angles greater than those between soil particles and water will have lower capillarity than soil of similar pore sizes. The surface properties of geotextile fibers, such as wetting angles, are affected by the polymers used and the manufacturing process. Unfortunately, the surface properties of geotextiles have been given very little attention (Bell et al. 1980). A test or means of estimating wetting angles between fibers and soil water or hydrophobicity of geotextiles would be useful.

If a fabric is relatively hydrophobic, this leads to the important consideration of whether it will trap water above the fabric surface. Allen et al. (1983) report that a threshold pressure of 7.5 cm (3 in.) of water was required to initiate flow through a particular melt-bonded polypropylene fabric. (The threshold pressure, being related to pore size and fiber wettability, also provides an indication of hydrophobicity [Allen et al. 1983].) Allen* reported ponding problems on the same fabric when it was draining under low positive pressures. Nothing has been found in the literature reviewed commenting on whether once flow is initiated it can be maintained by a pressure less than the threshold pressure.

Surface properties will also affect the moisture retention behavior and thus the unsaturated hydraulic conductivity of the geotextile. Unsaturated hydraulic conductivity indicates the ability to transport water under a suction gradient. Unfortunately, in the present study it was not possible to measure hydraulic conductivities of geotextiles at water contents corresponding to moisture tensions near the levels obtained in freezing soil.

It is important to remember that a geotextile interacts with soil particles when it is in place and it may not be able to be considered separately from the soil system. It has been treated separately here for convenience in discussing its behavior. Furthermore, the assumption is made that soil–fabric system properties are intermediate between the fabric

---

*Personal communication with T. Allen, Washington State Department of Transportation, Olympia Washington, 1986.

and soil alone. An important example is that of fabric thickness and hydraulic conductivity. It is not likely that when compressed by soil, Fibertex 400 is still ten times as thick as Typar 3401. Because of this circumstance, its hydraulic conductivity will be less than that reported by the manufacturers.

It is important to bear in mind that the laboratory frost heave tests utilized new geotextiles. Different test results may have been obtained if slightly damaged fabrics or fabrics previously subjected to wear had been used. Some of these effects could possibly be tested by repeated freeze–thaw tests, by damaging fabrics prior to testing or by using fabrics that have already been used in the field.

Contrary to the usual practice, no duplicate samples were tested in this program. In the standard CRREL frost heave test, duplicate samples are usually made and the highest heave rate of any sample is used for the frost-susceptibility determination. Rarely do the heave rates differ by more than 10% and most tests match each other to less than this amount.* For this reason, it will be assumed that test results are accurate to ±10%, but duplicate testing would be required for verification.

Effect of soil layering on frost heave. In an attempt to more closely approximate field conditions, frost heave laboratory specimens were made that consisted of silty sand on the top half and silt on the bottom half. Results of the frost heave tests on silt, siity sand and a silty sand–silt layered sample are presented in Figure 21. Contrary to what may have been expected, the layered specimen heaved less than the silty sand (shown as gravel on Figure 21) throughout the experiment; however, heave rates are nearly equal after an initial period of about 25 hours.

A comparison of initial frost penetrations shows that at 25 hours the silty sand had a frost penetration of about 56 mm (2.2 in.), whereas frost penetration in the layered specimen was about 82 mm (3.2 in.), over half of the total specimen height (the frost had penetrated past the interface). The same rapid freezing behavior was noted for the layered specimen containing Fibertex between the layers. The observed behavior may be ascribable to experimental variations.

* Personal communication with D. Carbee, CRREL, 1986.

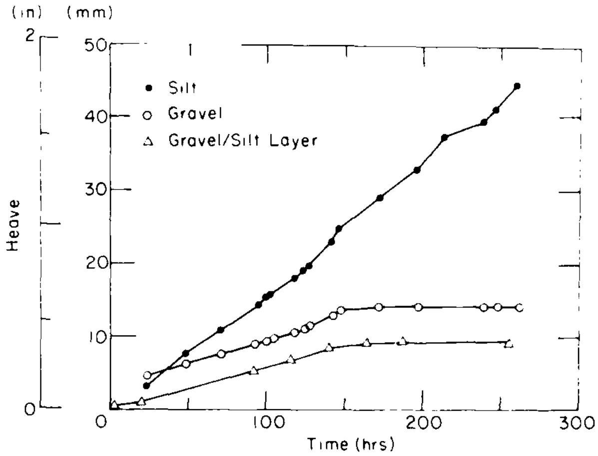


Figure 21. Frost heave of silt, silty sand (gravel) and silty sand–silt (gravel/silt layer) samples.

CONCLUSIONS

The two main objectives of the laboratory program were testing how well geotextiles can mitigate frost heave and characterizing the hydraulic properties and frost-susceptibilities of soils at Ravalli County Airport. (Hydraulic tests were also performed on several layers of Fibertex 400 stacked in a Tempe cell.) Both objectives were met.

The ability of geotextiles to mitigate frost heave in a highly frost susceptible silt and a silty sand of low frost-susceptibility was assessed by conducting standard CRREL frost heave tests with a geotextile disk inserted horizontally at mid-height in the samples. Two nonwoven polypropylene geotextiles, Fibertex 400 and Typar 3401, were tested in the silt. These geotextiles were selected because of past successful laboratory testing and because they have identical permittivities but different hydrophobic properties. One test series considered the effect of layering different soil types in a frost heave test.

No duplicate samples were made in the frost heave test series. Based on past test results, the assumption was made that repeatability would be within 10%, although further testing would have to be done to verify this. However, all of the laboratory testing would be more meaningful if duplicate tests were done.

Conducting frost heave tests using water chemically similar to the original soil pore water throughout the test, or using groundwater collected from the same location as soil samples, and comparing

test results with those that use distilled water throughout (the standard procedure), would reveal whether the current practice results in any significant error.

Laboratory results show that Fibertex 400 and Typar 3401 reduced heave in the silt by amounts ranging from 40 to 50%. Two layers of Fibertex 400 only reduced frost heave in the silt 5% more than did one layer. Observations made after the tests revealed that the geotextile in the specimen containing two layers of Fibertex 400 had moved a significant distance upward from original placement, probably because an ice lens formed below the geotextile. This may have affected the geotextile's ability to reduce heave.

Fibertex 400 was successful in reducing heave in sandy silt by 40–60% and in layered sandy silt–silt samples by about 20–70% (the heave reduction was only 20% at the end of the period). Water content distributions in the samples after the tests generally support the hypothesis that the geotextiles were acting as capillary breaks.

It is likely that the geotextiles' fiber surface properties and pore sizes influence their capillary behavior. The geotextiles may inhibit water flow at high suctions by having very low unsaturated hydraulic conductivities. More testing and research is desirable to better quantify the roles of fabric thickness and fiber surface properties in contributing to frost heave mitigation. If a fabric is relatively hydrophobic and has a relatively low hydraulic conductivity, there is a possibility that it will trap water above its surface, especially under low positive pressure. Standardized evaluation of the threshold pressure required to induce flow through a fabric would be useful.

Laboratory frost heave testing of geotextiles that have previously been subjected to wear would provide vital information on their potential use in the field.

Laboratory results showed, surprisingly, that a silty sand sample heaved more than a layered silty sand–silt sample; after an initial period of about 25 hours heave rates were approximately equal. Further testing of similar layered samples would help reveal whether this was attributable to experimental error or is an effect that deserves more attention.

In conclusion, it appears likely that geotextiles can be useful in mitigating frost heave in a variety of soil types. For maximum benefit, it appears that geotextiles should be placed between the depth of frost penetration and the water table. Future work should consider the effect of fabric depth in relation to frost penetration and the water table. Furthermore, more quantitative information regarding fiber surface properties and geotextile hydraulic characteristics would be helpful to someone trying to select the most appropriate geotextile for a given soil type. More research should be done to determine the actual effects of soil layering on frost heave behavior.

LITERATURE CITED

Allen, T., J.R. Bell and T.S. Vinson (1983) Properties of geotextiles in cold regions applications. Corvallis, Oregon: Transportation Research Institute, Transportation Research Report 83-6.

Andersson, O. and S. Freden (1977) The influence of a plastic fabric upon the pavement at a frost break. *Frost I Jord*, **18**: 43–50.

Bell, J.R., R.G. Hicks, J. Copeland, G.L. Evans, J.J. Cogne, P. Mallard, S. Jahn and M. Lewis (1980) Evaluation of test methods and use criteria for geotechnical fabrics in highway applications. Washington, D.C.: Federal Highway Administration, FHWA Report 80-021.

Berg, R.L. and T. Johnson (1983) Revised procedures for pavement design under seasonal frost conditions. USA Cold Regions Research and Engineering Laboratory, Special Report 83-27.

Beskow, G. (1935) Soil freezing and frost heaving with special application to roads and railroads. Swedish Geol. Society Series C, No. 375. Yearbook No. 3. (Translated by J.O. Osterberg, Technological Institute, Northwestern University.)

Casagrande, A. (1931) Discussion of frost heaving. *Proceedings of the Highway Research Board*, **11**: 168–172.

Chamberlain, E.J. (1981) Frost susceptibility of soil: Review of index tests. USA Cold Regions Research and Engineering Laboratory, Monograph 81-2.

Chamberlain, E.J. (1984) An automated soils freezing test. In *Proceedings: Second National Conference on Microcomputers in Civil Engineering, University of Central Florida.*

Chamberlain, E.J. (1986) Unpublished data. USA Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

Chamberlain, E.J. and D.L. Carbee (1981) The CRREL frost heave test, USA. *Frost I Jord*, **22**: 53–63.

Corté, A.E. (1962) Vertical migration of particles in front of a moving freezing plane. *Journal of Geophysical Research*, **67**(3): 1085–1090.

Derjaguin, B.V. and N.K. Melnikova (1958) Mechanisms of moisture equilibrium and migration in

soils. NAS/NRC Highway Research Board, Special Report 40, p. 43–64.

Gold, L.W. (1985) The ice factor in frozen ground. In *Field and Theory: Lectures in Geocryology*, Chap. 5. (Church, M. and O. Slaymaker, Eds.) Vancouver, Canada: University of British Columbia Press.

Hallet, B. (1978) Solute redistribution in freezing ground. *Permafrost: Third International Conference, Proceedings*. The National Research Council of Canada, Ottawa, p. 86–91.

Henry, K.S. (1987) Experimental results of standard CRREL frost heave tests with geotextiles conducted on soils from Ravalli County Airport, Hamilton, Montana. USA Cold Regions Research and Engineering Laboratory, Internal Report (unpublished).

Henry, K.S. (1990) A case study of potential causes of frost heave. USA Cold Regions Research and Engineering Laboratory, Special Report 90-9.

Hillel, D. (1982) *Introduction to Soil Physics*. New York: Academic Press.

Hoekstra, P. and R.D. Miller (1967) On the mobility of water molecules in the transition layer between ice and a solid surface. *Journal of Colloid and Interface Science*, **25**: 166–173.

Hoover, J.M., J.M. Pitt, L.D. Handfelt and R.L. Stanley (1981) Performance of soil-aggregate–fabric systems in frost-susceptible roads, Linn County, Iowa. *Transportation Research Record*, no. 827, p. 6–14.

Ingersoll, J. (1981) Method for coincidentally determining soil hydraulic conductivity and moisture retention characteristics. USA Cold Regions Research and Engineering Laboratory, Special Report 81-2.

Klute, A. (1965) Laboratory measurement of hydraulic conductivity of unsaturated soil. In *Methods of Soil Analysis*, Part I, *Agronomy 9*, Chap. 17. American Society of Agronomy, p. 253–261.

Mahar, L.J., T.S. Vinson and R. Wilson (1982) Effect of salinity on freezing of granular soils. *Proceedings, Third International Symposium on Ground Freezing, June, Hanover, N.H.* USA Cold Regions Research and Engineering Laboratory.

Riis, A. (1948) Frost-damage to roads in Denmark. *Proceedings, Second International Conference on Soil Mechanics and Foundations Engineering, Rotterdam*, vol. 2, p. 287–291.

Roth, H. (1977) Filter fabric for improving frost-susceptible soils. *Proceedings, International Conference on the Use of Fabrics in Geotechnics, Ecole Nationale Des Ponts et Chausses, Paris, April*, vol. 1, p. 23–28.

Soil Moisture Equipment Corp. (no date) *Operating Instructions for the Cat. No. 1400 Tempe Pressure Cell*. Santa Barbara, California: Soil Moisture Equipment Corp.

Taber, S. (1930) The mechanics of frost heaving. *Journal of Geology*, **38**: 303–317.

Taivenen, O.A. (1963) Preventative measures to reduce frost heave on highways in Finland. *Highway Research Record*, no. 33, p. 202–216.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
August 1990

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Laboratory Investigation of the Use of Geotextiles to Mitigate Frost Heave

5. FUNDING NUMBERS
722894.M7

6. AUTHORS
Karen S. Henry

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, New Hampshire 03755-1290

8. PERFORMING ORGANIZATION REPORT NUMBER
CRREL Report 90-6

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army
Office of the Chief of Engineers
Washington, D.C. 20314-1000

U.S. Department of Transportation
Federal Aviation Administration
Research and Development Service
Washington, D.C. 20591

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DOT/FAA/RD-90/13

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.
Available from NTIS, Springfield, Virginia 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

Frost action beneath pavements can lead to several problems, including thaw weakening, which leads to cracking and subsequent pumping of fine soil particles onto the surface, as well as hazardous conditions caused by differential heaving. This study utilized data and frost-susceptible soil collected at Ravalli County Airport, Hamilton, Montana, to study the use of geotextiles to mitigate frost heave. The ability of geotextiles to reduce frost heave in subgrade material by creating a capillary break was assessed by inserting disks of fabric in soil samples and subjecting them to laboratory frost heave tests. Frost heave tests were also conducted to classify the frost-susceptibilities of soils at the airport. Soil moisture characteristics and unsaturated hydraulic conductivities were determined for soils tested as well as for one of the geotextiles used. Results of the laboratory investigation indicate that certain geotextiles show promise for use as capillary breaks. In laboratory tests, the presence of geotextiles led to the reduction of frost heave by amounts up to about 60%. It is speculated that the capillary break action provided by the geotextile is attributable to the pore size and structure of the material and the surface properties of the fibers.

14. SUBJECT TERMS
Frost heave; Frost heave mitigation; Frost susceptible soils; Geotextiles; Pavement

15. NUMBER OF PAGES
37

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

☆ U. S. GOVERNMENT PRINTING OFFICE: 1990--700-057--22027